428

N 62 14921

NASA TN D-1293

NASA TN D-1293

TECHNICAL NOTE

D-1293

TELEMETERING INFRARED DATA FROM THE TIROS METEOROLOGICAL SATELLITES

J. F. Davis, R. A. Hanel, R. A. Stampfl,
M. G. Strange, and M. R. Townsend

Goddard Space Flight Center
Greenbelt, Maryland

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON August 1962

H

TELEMETERING INFRARED DATA FROM THE TIROS METEOROLOGICAL SATELLITES

by

J. F. Davis, R. A. Hanel, R. A. Stampfl,
M. G. Strange, and M. R. Townsend
Goddard Space Flight Center

SUMMARY

All the TIROS satellites contain television cameras which acquire cloud cover information. TIROS II and III also have scanning and fixed radiometers to measure infrared and reflected solar radiation from the earth and its atmosphere. The scanning radiometer is mounted so that the satellite's optical axis is inclined 45 degrees to its spin axis. The spin motion provides a scan of individual lines of the earth's surface, and the orbital motion provides line advance. Spin and optical resolution are such that the information bandwidth is 8 cycles.

Five choppers and filters separate the radiation into five channels whose outputs modulate the frequencies of five subcarrier oscillators. For maximum efficiency, each one is a basic phase-shift oscillator with a balanced input stage. The gain of the two balanced branches and the resultant phase shift in the network are functions of the input voltage, which thus determines the frequency of oscillation. Center frequencies are nonstandard and, to transmit the five channels within minimum bandwidth, frequency converters and crystal filters must be used for demultiplexing.

A mechanical commutator samples the outputs from the nonscanning radiometer, thermistors, calibration resistors, and a pressure sensor. Each of these 6-second samples modulates, in turn, the frequency of a sixth subcarrier oscillator, a true phase-shift oscillator. These six signals and a reference oscillator signal are mixed and recorded on a single-channel tape recorder. Ground command initiates high speed playback and turns on an FM transmitter, which is modulated by the playback voltage.

The composite signal is recorded on magnetic tape at a ground station and then shipped to GSFC where it is demultiplexed and converted to digital format for an IBM computer. The final data processing generates maps of isoradiance lines. This paper discusses the system design, circuits, test parameters, and performance of the TIROS infrared radiation experiment.

CONTENTS

TELEMETERING INFRARED DATA FROM THE TIROS METEOROLOGICAL SATELLITES

by

J. F. Davis, R. A. Hanel, R. A. Stampfl,
M. G. Strange, and M. R. Townsend
Goddard Space Flight Center

INTRODUCTION

The satellites TIROS II (1960 π_1) and III (1961 ρ), like their successful forerunner TIROS I (1960 β), carry television cameras for cloud cover analysis. In addition, TIROS II and III each contain two radiometer systems to measure infrared and reflected solar radiation from the earth and its atmosphere (Reference 1). From these functions the satellite series derived its name: Television Infra-Red Observation Satellite.

If the satellite is within communication range of a ground station, the television system can be commanded to take direct-pictures (real time transmission). It can also be programmed to record 32 pictures over a selected area. The pictures are then transmitted when the satellite is within acquisition range of a ground station. The radiometer signals, however, are recorded continuously and then transmitted upon command, in time-compressed form.

The satellite's medium resolution (scanning) radiometer has optics which scan the earth as the satellite spins. Signals from space, which are essentially zero, and signals emitted and reflected from earth or cloud tops according to their individual temperatures and albedo, are reflected through a prism onto five rotating disks, half mirrored and half black. Radiation from the sky and the earth is alternately reflected from the mirror portion of each disk through five separate filters, each of which passes radiation of selected wavelengths through a separate lens onto a separate detector. The other radiometer is a low resolution (nonscanning) instrument that performs heat balance measurements of the earth. By sensing the temperatures of both a white and a black detector, the experiment discriminates between thermal radiation (far infrared) and reflected sunlight. The telemetering and presentation of the infrared signals will be discussed in this paper.

All three TIROS satellites achieved nearly circular orbits. Table 1 summarizes the individual characteristics.

Table 1
Orbital Characteristics of TIROS I, II, and III

Element	TIROS I	TIROS II	TIROS III
Date Launched	April 1, 1960	November 23, 1960	July 12, 1961
Perigee (statute miles)	432.9	385.6	458.27
Apogee (statute miles)	464.4	454.4	508.62
Period (minutes)	99.24	98.27	100.41
Inclination (degrees)	48.39	48.53	47.90

Figure 1 shows the base plate of TIROS II. The circular area in the center is the separation spring seat; towards the rear one of the TV camera lense protrudes from the baseplate. In the opposite direction the slit in the center rectangular section and the opening on the satellite wall serve as viewing ports for the scanning radiometer. The small circle to the left is the opening for the low resolution radiometer.

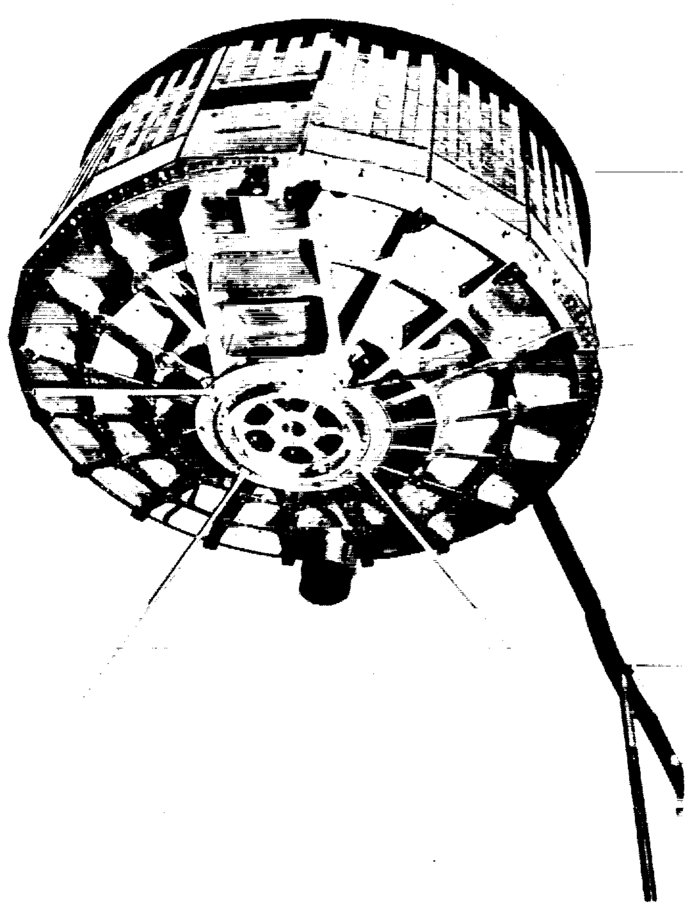


Figure 1 – Base plate of the TIROS II meteorological satellite

RADIATION EXPERIMENT

The five-channel scanning radiometer* (Figure 2, References 2 and 3), has an optical axis which is inclined to the spin axis by 45 degrees. Each of the channels has a 5-degree field of view; and each scans the earth and outer space, alternately, as the satellite spins on its axis. Radiation inputs arrive simultaneously, from opposite directions, through the wall and base of the satellite.

The field of view of the optical system mounted on the spinning satellite provides consecutive scanning sweeps of the surface of the earth. Since the orbital motion of the satellite provides the advancement from one sweep line to the next, the optimum field of view yields neither overlap nor incomplete coverage. The actual coverage varies with spin rate, altitude, and viewing angle.

*The radiometer was manufactured by the Barnes Engineering Co.

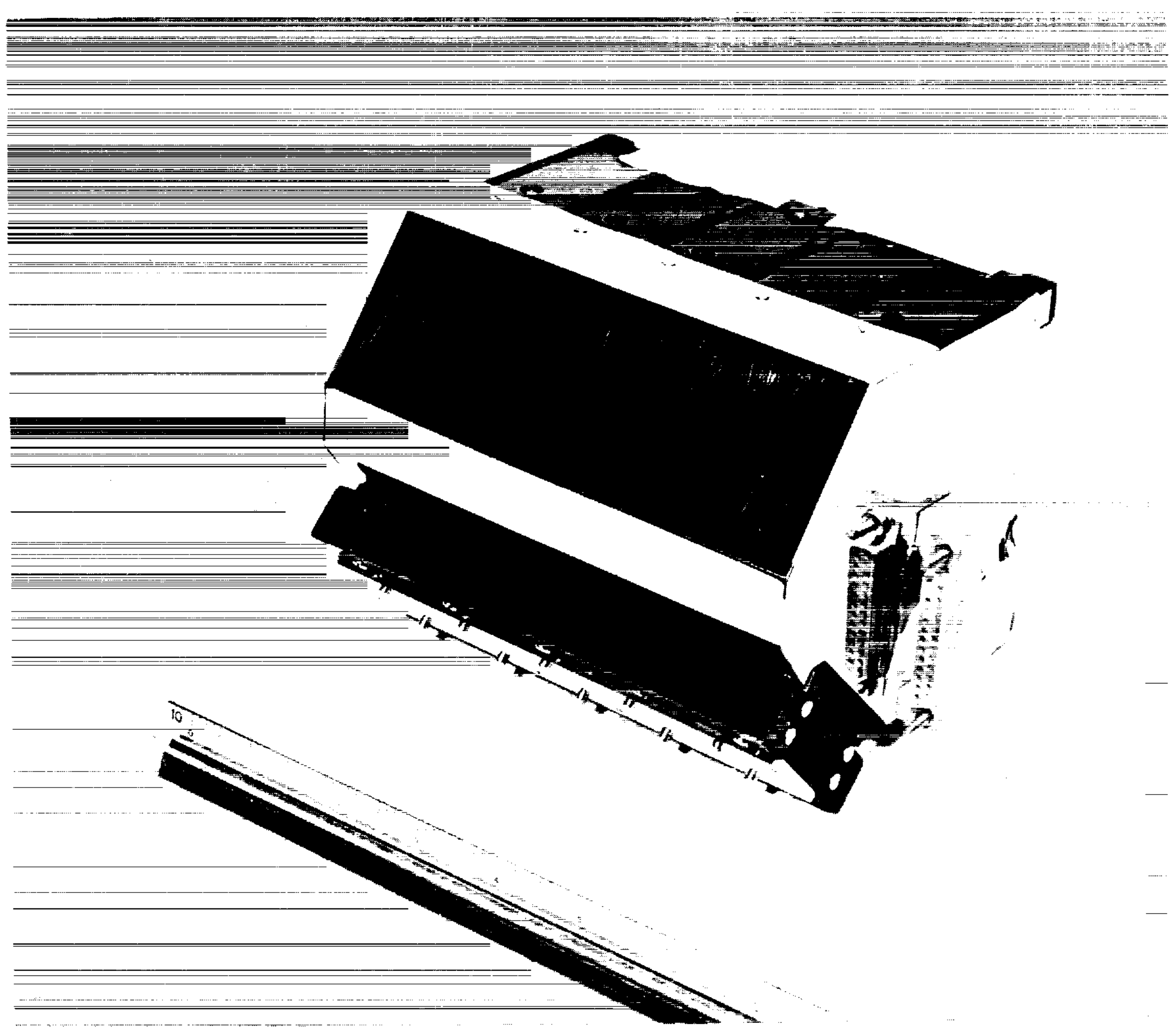


Figure 2 – View of the 5-channel scanning radiometer

As the spin rate decreases because of interaction between the satellite and the earth's magnetic field, spin-up rockets around the periphery of the satellite can be fired in pairs to bring the spin of the satellite back within the design limitations of the experiment.

Figure 3 shows examples of scan patterns that can be swept out on the earth by the spinning satellite. The pattern is a circle wherever the spin axis coincides with the earth radius vector. When the spin vector is normal to the earth radius vector, the ends of the optic view the earth alternately. The result appears as a pair of hyperbola-like branches in the figure. When the spin vector neither coincides with nor is normal to the earth radius vector, one end of the optic alternately views earth and sky and the other scans only the sky.

Since the field of view, 5 degrees, and the spin rate, 10 rpm, are known, it is possible to compute the frequency spectrum required by the storage and communication links. The

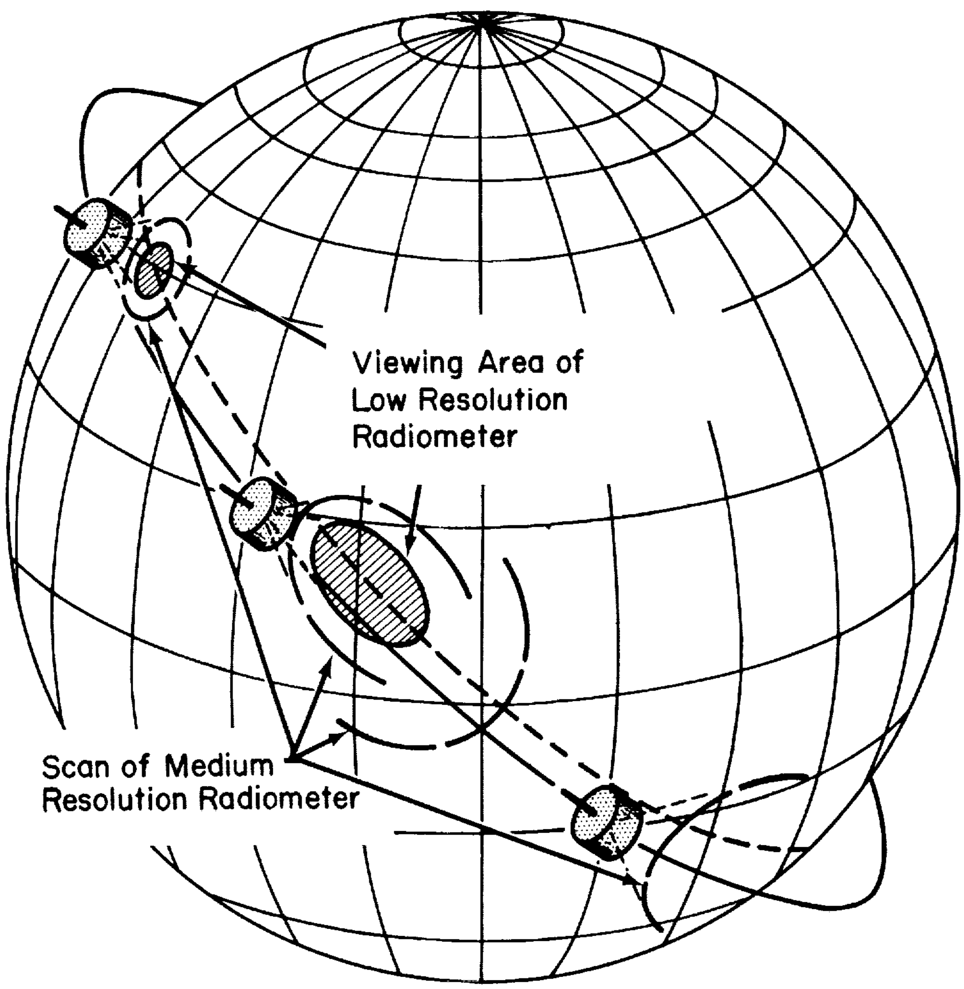


Figure 3 – Geometry of the scanning motion of the medium resolution radiometer and of the viewing area of the low resolution radiometer

frequency spectrum of a scanning slit has a $(\sin x)/x$ characteristic. The first null, at $x = \pi$, is characterized by the following equation:

$$\frac{2\pi \sin \phi}{\alpha} = \frac{f_0}{n} \tag{1}$$

where

α = field of view, 5 degrees,
ϕ = angle between spin axis and optical axis, 45 degrees,
f_0 = first null frequency,
n = spin rate.

The value for f_0 is found to be 8.4 cps. It is common to restrict the bandwidth to a value below the frequency at the first null, since the signal power above that point is insignificant and the phase above it is highly distorted. Therefore an information bandwidth of 8 cps was chosen.

Medium Resolution Radiometer

The medium resolution radiometer has lens materials and filters which restrict the sensitivities of its five channels to the following spectral regions:

(1) 6 to 6.5 microns — water vapor absorption;
(2) 8 to 12 microns — atmospheric window;
(3) 0.2 to 6 microns — reflected solar radiation;
(4) 8 to 30 microns — thermal radiation;
(5) 0.55 to 0.75 microns — visible reference and daytime cloud cover.

An example of one of the medium resolution radiometer channels is diagrammed in Figure 4. The chopper disk, which has a half-mirrored, half-black surface, alternately reflects radiation from the scan beam and from the reference beam through the filter and lens to the thermistor bolometer. A single six-pole ac motor drives the five (identical) chopper disks at 46 revolutions per second. The alternating voltages thus generated at the thermistor bolometers are proportional to the difference in radiation energy coming from the two opposite directions (through the wall and base). This ac voltage is amplified and rectified in a balanced diode network. The five channels have identical circuitry, except for an additional preamplifier stage in the 6 to 6.5 μ channel. The outputs are fed to the instrumentation package for telemetering to the ground station.

The measurement with the worst signal-to-noise (S/N) ratio is that in the water vapor band (6 to 6.5 μ), since all the other bands have much higher energy levels. Therefore, the signal-to-noise ratio of that channel will be analyzed here.

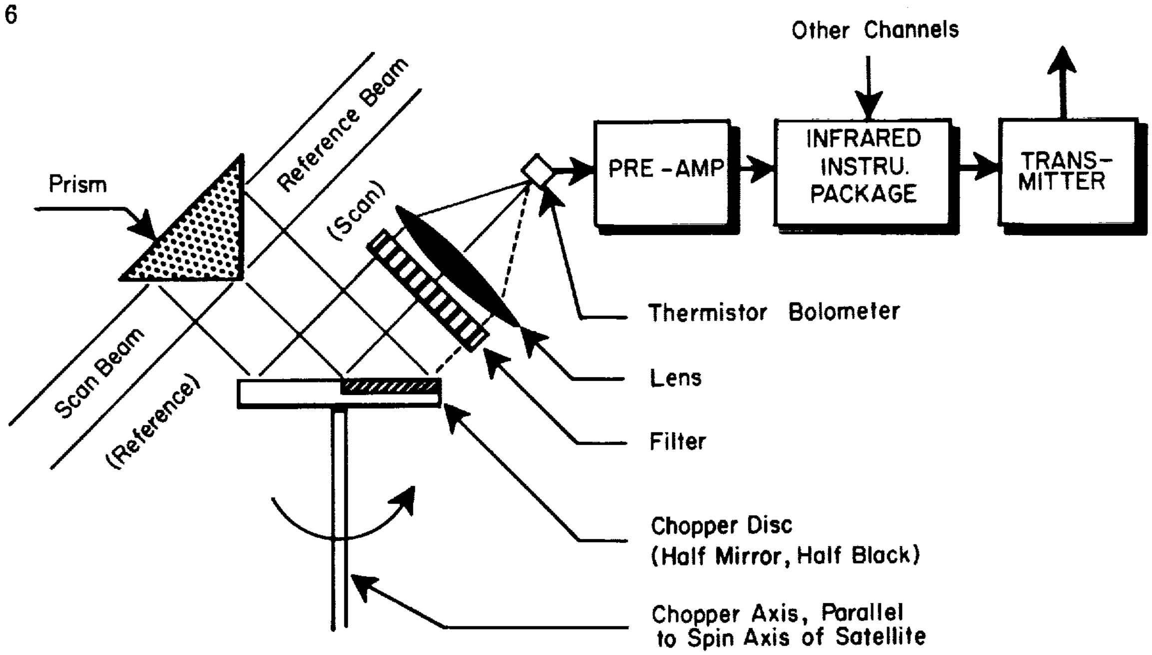


Figure 4—Block diagram of a radiometer channel

The S/N ratio can be calculated from the signal power which reaches the thermistor bolometer and the noise equivalent power of the detector. The signal power is

$$P_s = \frac{1}{\pi} A_O \overline{W} \omega F \tag{2}$$

where

A_O = area of optic in cm^2,
$\overline{W}$ = radiant emittance of source in w/cm^2,
ω = solid angle of view in steradians,
F = filter transmission factor.

If the earth is assumed to be a 260°K blackbody with a radiant emittance of 0.026 w/cm^2, then the energy within the 6 to 6.5 μ band is 1 percent of this or 2.6×10^{-4} w/cm^2. Assuming also, an F number of 1 for the optical system (a 40 percent filter transmission factor) and a 1 mm^2 bolometer, P_s is 2.6×10^{-7} watt.

The noise equivalent power (Reference 4) is

$$NEP = 10^{-8} \sqrt{\frac{A_D \Delta f}{250\,\tau}} \tag{3}$$

where

A_D = detector area in mm^2,
Δf = signal bandwidth in cps,
τ = time constant of bolometer in milliseconds.

If we assume a detector area of 1 mm^2, a noise bandwidth of 16 cps within the signal band of 46 ± 8 cps, and a time constant of 2.2 milliseconds, then NEP is 1.7×10^{-9}. The S/N ratio may then be calculated as 150:1. In practice this number is never reached, chiefly because bias voltage on the bolometers cannot be kept optimum over the wide temperature range involved. Another deterrent is flicker noise in the input stage. Actual S/N ratios of 30:1 (30 db) have been obtained for this channel. An analysis of the other four channels shows that their S/N ratios are better, even when the higher noise figure of the transistor amplifier is considered.

Low Resolution Radiometer

The low resolution radiometer channels (Figure 5 and Reference 5) are not modulated by the spin of the satellite because their optical axes are parallel to the spin axis. Their 50-degree field of view observes an area which is within the field of the wide angle television camera. Figure 3 shows a comparison between the viewing area of the nonscanning radiometer and that scanned by the medium resolution radiometer. One of these two low-resolution radiometer channels consists of a black bolometer detector and the other of a white one, each of which is mounted in the apex of a highly reflective cone. The black detector is equally sensitive to reflected sunlight and to long wave terrestrial radiation. The white cone is coated to be reflective in the visible and near infrared; thus, it measures only thermal radiation. These bolometer detectors present the instrumentation package with resistances which vary with radiation. From the detected values the heat balance of an area can be computed.

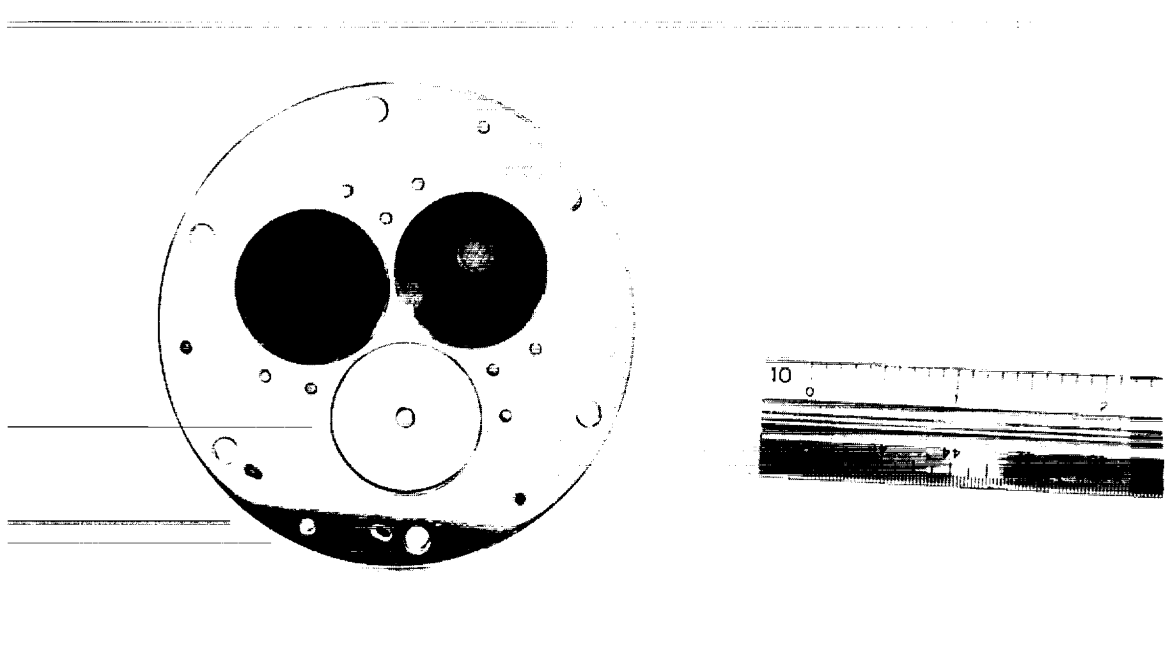


Figure 5—View of the low resolution radiometer

Monitoring the Experiment Parameters

The performance of the satellite instrumentation must be monitored, both for engineering reasons and also to permit the adjustment of operational programs. In contrast to larger satellite or spacecraft systems, the housekeeping-type telemetry for the TIROS infrared (IR) package is limited to only a few temperature and pressure test points. Instrumentation is pressurized to one atmosphere; a Fairchild TP-100 pressure transducer is used to monitor the pressure. This type of transducer contains a diaphragm whose movement is transferred to a lever on a variable resistor. Thus, pressure variations are converted into resistance variations.

Temperature measurements are made of both radiometer housings and of the inside of the electronics package. Precision thermistor networks were designed so that a particular resistance value corresponds to a specific temperature. A resolution of 0.2°C is obtainable.

SYSTEM DESCRIPTION

The TIROS IR telemetry uses an FM/FM system with PAM/FM/FM (PAM—pulse amplitude modulation) for one channel. Frequency modulation techniques were chosen for the subcarriers and the VHF transmitter in order to minimize unwanted interference.

The 16 pound TIROS IR instrumentation package with its component parts is shown in Figure 6. To the left, in back, is the tape recorder, including the time-sharing switch. The inch-deep unit in the front is the dc-dc converter* potted in Eccofoam. To its right is the main deck with all nine plug-in modules clearly shown. These modules are the five subcarrier oscillators (the five FM channels), the channel 6 phase shift oscillator (the PAM channel), the channel 7 tuning fork oscillator, and the record and playback amplifiers for the tape recorder. To the right, in back, is the speed control unit for the tape recorder playback motor; the VHF transmitter† seen in front of it is housed in this same unit. The total IR system power is less than 5 watts during the record cycle and less than 30 watts during the 3-1/3 minute playback cycle.

The components had to pass severe environmental tests, both separately and as a unit. During vacuum-thermal tests, temperatures were varied from 0° to 60°C with data continually readout. The instrumentation package was designed to survive 20 g rms random noise vibration and 10 g peak sinusoidal vibration, from 5 to 2000 cps.

Seven frequency bands are employed for the telemetry. Each of the five subcarrier oscillator FM channels is 50 cps wide and the PAM channel is 60 cps wide to allow for

*Designed by Frederick Engineering Corporation, Frederick, Maryland.

†Telechrome VHF Transmitter Model 1483-A4.

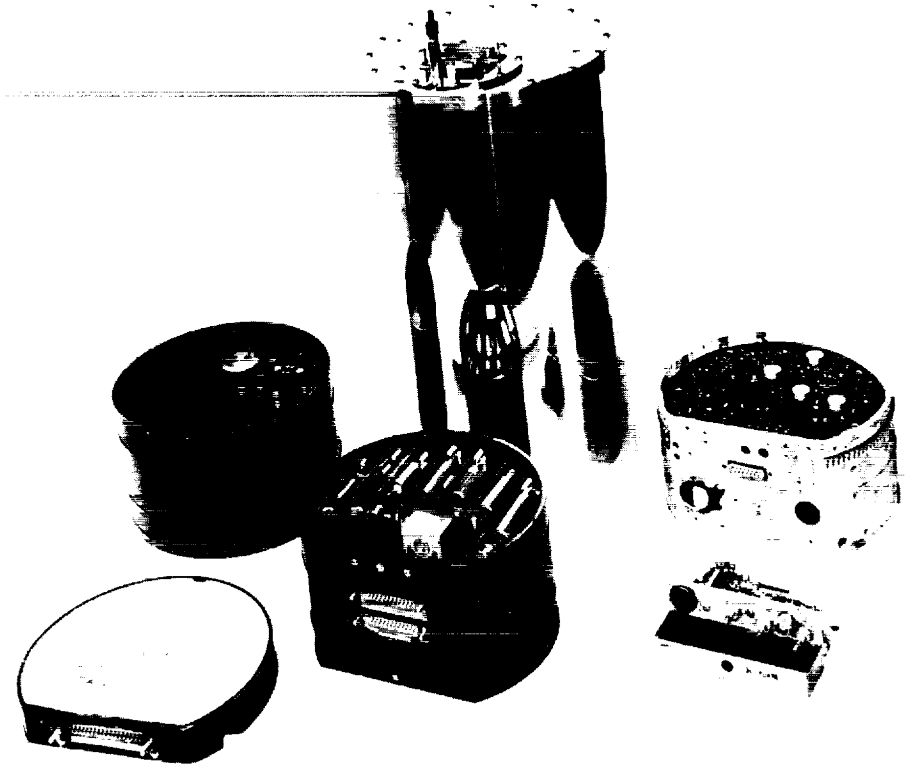


Figure 6—The TIROS instrumentation package

the frame synchronization signal. Channel 7 is a single frequency for reference. The spacing between channels is 15 cps. Constant bandwidths are maintained and deviations vary from 20 to 6.5 percent as the center frequencies of the channels increase. These characteristics were chosen in order to keep the total bandwidth requirements consistent with the limitations of the miniature tape recorder which records the multiplexed signals. System parameters were chosen so that the tape recorder itself, specifically the magnetic tape and the constancy of speed in the drive mechanism, became the limiting factor in the achievable signal-to-noise ratio. For example, to maintain a 50 cps bandwidth which would include flutter and wow variations, the dynamic range of each subcarrier was reduced to 45 cps.

Figure 7 shows how the satellite instrumentation operates. The chopped radiation detected by the thermistor bolometers of the scanning radiometer is amplified, rectified, and processed to produce a push-pull output voltage of 0 to plus and minus 6 volts. Push-pull signals are used wherever possible to minimize pickup. These five output signals drive the five phase-shift subcarrier oscillators, which have a stability of ± 2 percent of bandwidth from 0° to 50°C. Since the coldest signal corresponds to outer space, only increasing voltages can be generated. These voltages deviate the voltage controlled oscillators up to 50 cps (Figure 7). Hence, a modulation index of 3 is used for the highest information frequency, 8 cps.

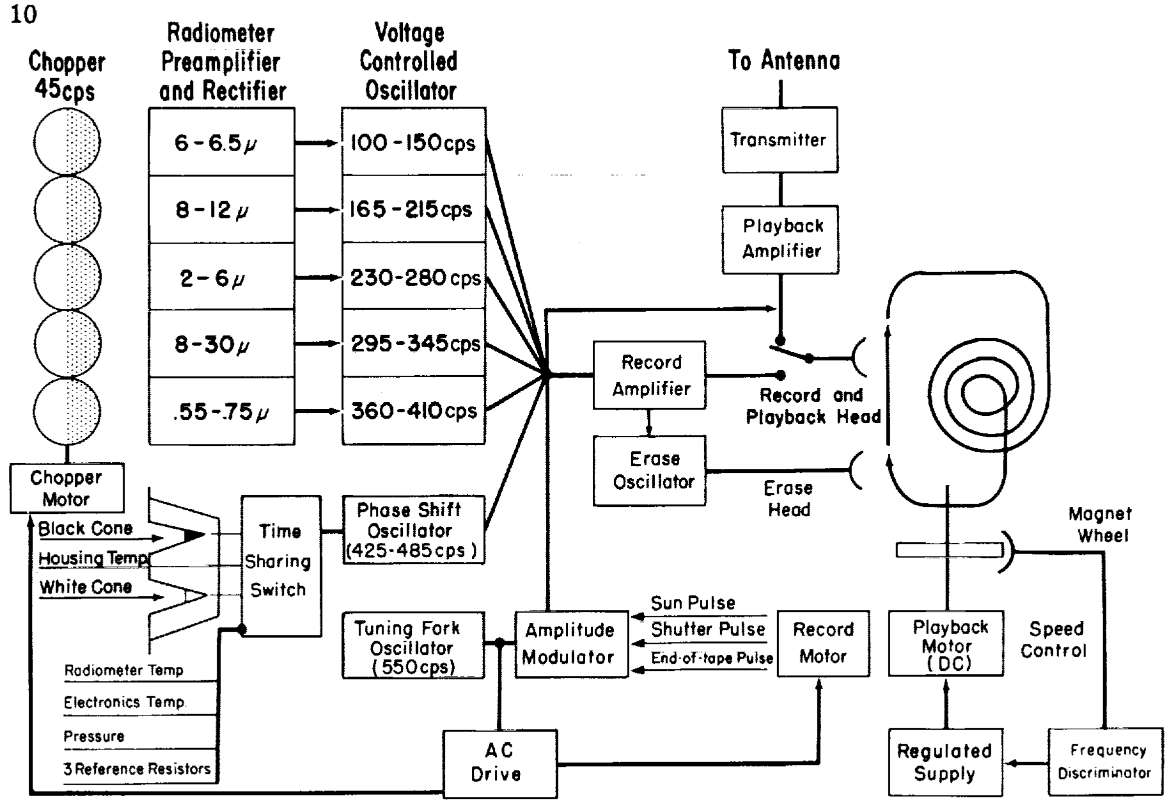


Figure 7—Block diagram of TIROS instrumentation

Channel 6 employs a conventional phase-shift oscillator whose output frequency can be made almost linearly proportional to resistance, since its total bandwidth is only 10 percent of its center frequency. The appropriate resistance value is switched in by a mechanical commutator, which is an integral part of the tape recorder (Reference 6). This is a time-sharing channel, collecting the data from the nonscanning radiometer, the three reference temperatures, the canister pressure, and the fixed calibrations generated by reference resistors. Each frame contains forty samples of 6 seconds each. Four samples, which include the low resolution radiometer data, are located in the first four positions of a five position switch and are sampled every 30 seconds. The fifth position is subcommutated and contains the housekeeping and calibration references which are sampled only once per frame or every 4 minutes.

Channel 7 is a tuning fork oscillator which generates 550 cps. The frequency was chosen as the upper band limit of the tape recorder and serves as a timing reference for the data, with amplitude modulations denoting sun pulses, correlation with TV pictures, and interrogation times. This signal also provides the frequency necessary to drive the synchronous motors of the tape recorder and the radiometer chopper. Its presence permits compensation in the ground equipment for errors due to wow and flutter.

The amplitude stability of tape recorded signals is poor. For this reason, modulation of the timing signals is limited to two levels: -40 and -95 percent. The transition as the satellite enters or leaves sunlight, and the angle between the horizon and the sun are of interest in quick-look evaluations of satellite data and also for comparison with temperature data.

Around the circumference of the satellite cylinder there are nine narrow angle slots, each having an acceptance angle of almost 180 degrees (Figure 1). Thus the sun, in almost any position, can generate pulses as the satellite spins. The system permits sun angle determination for TV pictures. One of the nine detectors generates a 0.5 second pulse which amplitude-modulates the tuning fork oscillator signal by -40 percent. In order to establish correlation between the IR data and the TV pictures, a 1.5 second timing pulse is generated with each camera shutter pulse. This also amplitude-modulates the reference signal by -40 percent. A third timing signal, a 1.0 second pulse, causes the reference signal to drop almost to zero. It is initiated at approximately the same time as the ground readout command, which is derived from WWV synchronized clocks located in the readout stations. Thus, an absolute time marker is recorded on the magnetic tape. As a by-product, rather accurate times of picture taking can be determined at the ground station by visual inspection of a record of the timing signal.

The tape recorder records continuously, at 0.4 ips, the sum of the seven signals described above: the five subcarrier signals from the scanning radiometer; the time-shared channel signal with the wide field (nonscanning radiometer) data and housekeeping data; and the reference signal which is amplitude modulated with sun pulses, TV pulses, and the interrogation time pulse. This composite signal is recorded on a 200 foot continuous loop of 1/4-inch 1-1/2-mil lubricated instrumentation tape which stores 100 minutes (approximately one orbital period) of data.

The readout command, generated from the ground when the satellite is within acquisition range, turns on the transmitter filament voltage and causes a half-minute delay. After this delay, plate voltage is applied to the 1.8-watt 238-Mc transmitter and the playback motor of the tape recorder is turned on. The playback speed, 12 ips, is 30 times faster than the record speed, so one orbit is read out in 3.33 minutes and the playback frequencies are 30 times higher than the record frequencies. During the playback cycle, the real-time composite signal, with all seven inputs continuously operating, is added in the playback amplifier to the playback signal; and this combined signal (100-550 cps; 3-16.5 kc) is the transmitter input. After one cycle of the tape loop, a reset switch activated by a gear train in the tape recorder resets the system to the record mode.

Signal-To-Noise Ratio Limitations

Computations of the output noise levels for individual channels can be performed in the conventional way. They show a modulation improvement by a factor between 2 and 8 even without applying pre-emphasis to the subcarriers. Critical consideration of the limitations on noise and accuracy quickly reveals that the most severe problem is in the tape recorder. The magnetic tape used was selected because it had an amplitude stability better than 26 db. Since this type of amplitude modulation affects the FM carriers very little if the discriminators are designed properly, the stability value was critical only with regard to the timing channel, where a 20 db signal-to-noise ratio was desirable. A high erase level makes residual tape noise negligible.

The predominant factor contributing to decrease in the output signal-to-noise ratio is variability in the tape recorder speed. Analysis of the wow and flutter spectrum showed that the components between 0 and 300 cps, which are significant for the information bandwidth, generate a 1.5 percent peak-to-peak variation. This is especially significant in the higher frequency subcarrier channels where it is about 10 percent of the channel bandwidth. This noise level is considerably worse than the noise contribution at average telemetry ranges. The 30:1 record-to-playback speed ratio is maintained to within ± 1 percent by a servo loop. This variation, and part of that which is due to tape recorder wow and flutter, can be compensated for in the ground equipment through the use of the reference oscillator signal. Another accuracy limitation concerns the basic stability of the subcarrier oscillators over the operating temperature range. Drift is kept at less than ± 1 cps (4 percent of bandwidth), but that amount is a significant factor in loss of accuracy. Accurate calibration records made before launch can be used for partial compensation of this drift, since the subcarrier oscillator temperature is known quite accurately from the telemetry. The final limitation on drift results from the repeatability of measurements which depend on component aging. One set of subcarrier oscillators tested for over three months showed less than 1 cps drift from aging. Table 2 summarizes the instrumentation S/N ratio limitations.

Table 2

Instrumentation Signal-to-Noise Ratio Limitations

Source	Signal-to-Noise Ratio
Tape	26 db, not significant on FM channels
Subcarrier oscillator drift due to temperature	14 db, compensated to 34 db by calibration curves
Wow and flutter	34 to 17 db, compensated to 44 to 27 db in ground station equipment
Radiometers	30 db, for worst detector channel

Data Transmission and Acquisition

Since acquisition look angles are known from a program established by the TIROS Control Center, data can be acquired from the satellite as soon as it comes over the horizon, 1900 miles from the acquisition station in question. The system parameters listed in Table 3 show that the carrier signal-to-noise ratio even at the horizon is well above threshold and will exceed 30 db in many cases, depending on the slant distance between the satellite and the acquisition station. Larger margins than the ones shown in Table 3 rarely occurred in actual operation, because of the careful design of the turnstile antenna pattern in the satellite and the use of polarization diversity at the readout stations. The S/N ratio variations which were due to imperfections in the antenna pattern and in the adjustment of the diversity combiners remained well below the variation that was due to the differing range. Noise in the receiver and noise that was due to sky radiation were negligible because of the high-gain ground antenna and adequate transmitter power.

Table 3

TIROS System Parameters

Range at horizon:	1900 mi
Orbital altitude:	450 mi
Path attenuation at horizon:	150 db
Path attenuation at zenith:	137 db
Satellite antenna gain:	-3 db
Ground antenna gain (60-foot dish):	27 db
Antenna temperature:	290°K
Cabling and hybrid losses:	-2 db
Transmitter frequency:	238 Mc
Transmitter power:	1.8 w
Receiver bandwidth:	100 kc
Receiver noise figure:	5 db
S/N at horizon:	26 db
S/N at zenith:	39 db

Two data acquisition stations were used for TIROS II, one at the U. S. Army Signal Corps Research and Development Laboratories, Fort Monmouth, New Jersey, and the second at the Pacific Missile Range, San Nicolas Island, California. For the TIROS III tests the NASA Field Station, Wallops Island, Virginia, replaced the Fort Monmouth station.

The output of the diversity combiner is recorded FM on magnetic tape and shipped to the Goddard Space Flight Center for processing. Figure 8 shows the parallel path that

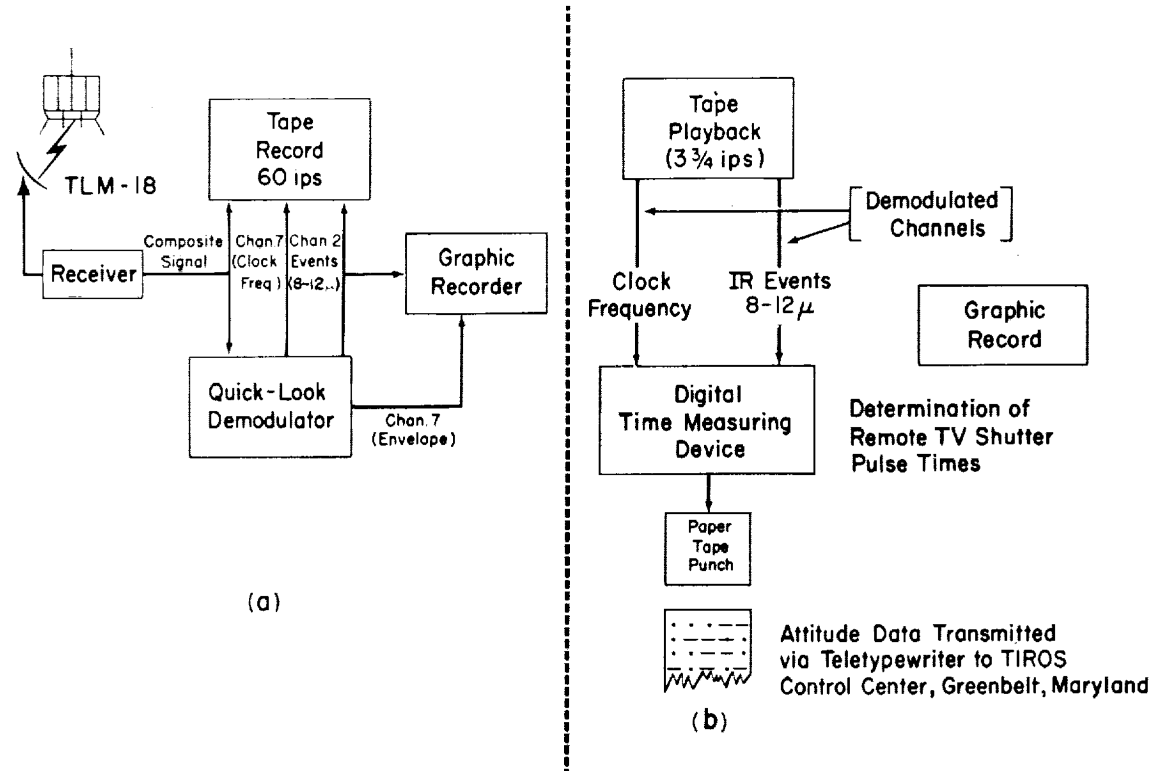


Figure 8—Block diagram of the readout station

a signal takes at a data acquisition station. One thermal channel of the five-channel scanning radiometer is filtered, demodulated, clipped so that only horizon crossings are displayed, and recorded on one channel of a two-channel pen recorder. The other channel records the rectified envelope of the timing signal, displaying the sun pulse and TV shutter pulse modulation as well as the interrogation pulse. This permits coarse picture time correlation at the ground stations and an immediate check on the satellite.

The clipped horizon-crossing signals and the reference timing channel are recorded on tape at the ground stations and played back at 1/16 record speed. The number of cycles of the reference frequency occurring between horizon crossings is counted and recorded on punched paper tape for transmission, over teletype lines, to the TIROS Technical Control Center at Greenbelt, Maryland. From these tapes plus a knowledge of the satellite's spin rate and orbital position, the attitude of the satellite can be computed on automatic data processing equipment. An error of less than 3 degrees has been achieved under optimum conditions. For TIROS III, attitude is computed at the readout station.

Ground Station Operation

The processing method for data mailed to the Goddard Space Flight Center is illustrated in Figure 9. The composite signal is played back, demultiplexed, demodulated, decommutated, and digitized. Analog outputs of all seven channels are recorded for visual inspection. The 550 cps tuning fork reference signal, 16.5 kc on playback, is used to compensate for tape recorder speed errors by two methods. One compares the 16.5 kc signal to a crystal reference frequency and varies the speed of the ground station tape recorder at a rate up to one cycle per second. The other corrects the signals at the demodulator outputs to compensate for frequency errors of ± 250 cps.

The demodulator* can be seen in detail in the block diagram of Figure 10. The composite signal is amplified; the real-time signal is filtered, amplified, and terminated at a separate output. The presence of this signal is used as a control to actuate a squelch

*The demodulator was constructed by Tele-Dynamics Division, American Bosch Arma Corporation.

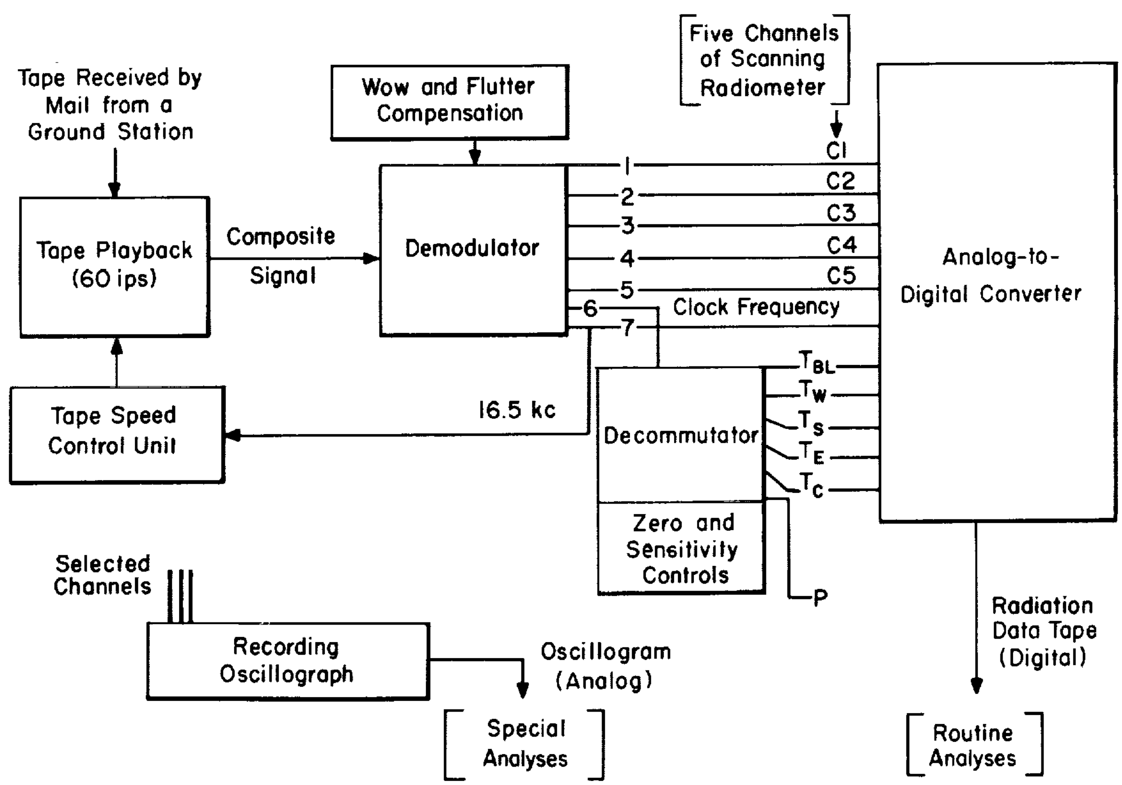


Figure 9—Block diagram of the data processing operation at GSFC. T_{BL} is the temperature of the black cone and T_W that of the white cone of the low resolution radiometer; T_S is the reference temperature of the low resolution radiometer, T_E that of the package, T_C that of the radiometer housing, and P is the pressure in the sealed canister.

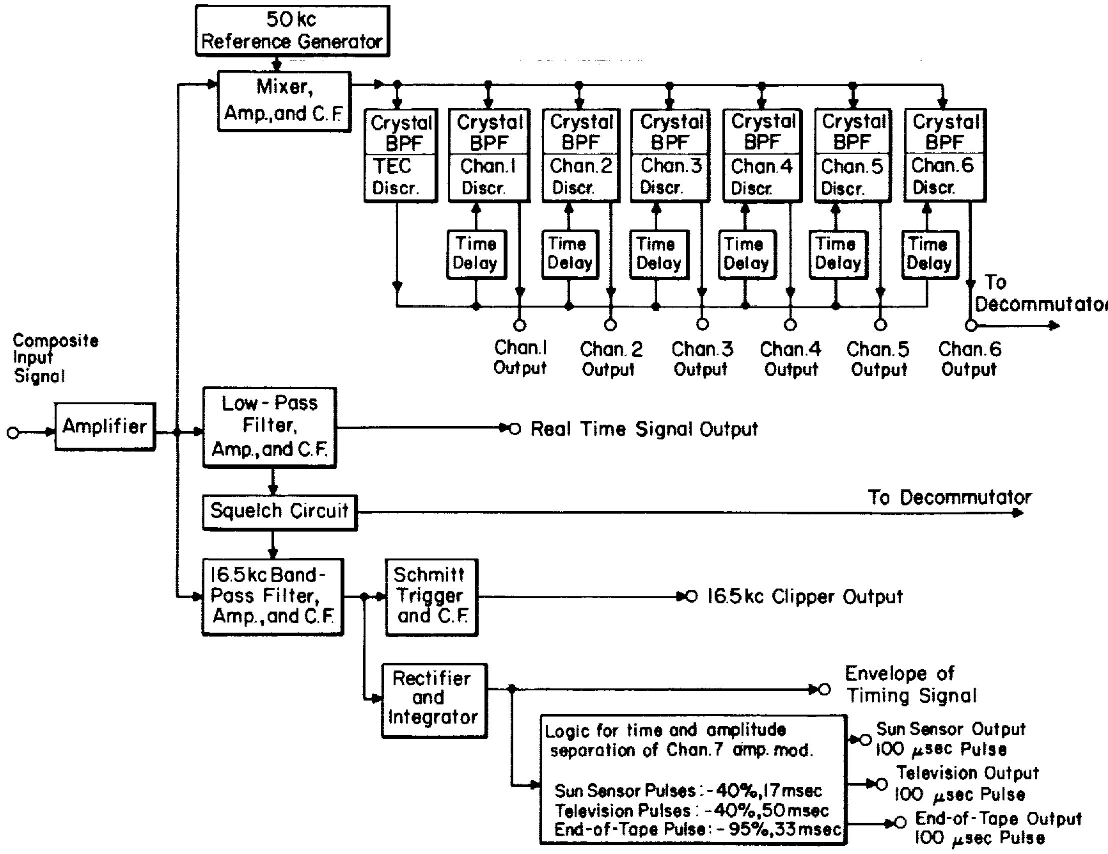


Figure 10—Block diagram of demodulator. TEC is tape error compensation and BPF is bandpass filter.

circuit which normally prevents the Channel 6 output from reaching the decommutator and maintains the decommutator in a ready condition.

The envelope of the 16.5 kc reference signal, showing the sun pulse, TV pulse, and end-of-tape (EOT) pulse modulations gives a quick check on the amplitude stability of the tape recording systems. These modulated signals are separated by a logic circuit which senses both the duration and the amplitude of the signals and presents 100 μsec output pulses as they occur. A pulse-shaping circuit generates a square wave output from the 16.5 kc signal which is used as the external clock for the analog-to-digital converter. When the 16.5 kc signal is lost because of fading, filtered noise is amplified and clipped to provide this clock. This "flywheel" effect minimizes timing errors during signal fades.

With the narrow guard bands in this system, crystal filters were used because of their high rate of attenuation outside the passband. In order to obtain crystal filters with an amplitude response sufficiently flat over the required 1500 cps band, and of a size suitable for fitting in a standard Tele-Dynamics modular 2202 discriminator, it was necessary to translate the composite signal by 50 kc to between 53 and 66.5 kc. Instability in the crystal oscillator is negligible. The filters obtained for these frequencies, designed to be driven from a constant current source, have amplitude variations as high as 6 db over their passbands.

Standard IRIG 52.5 kc discriminators, with a linearity of 0.25 percent, were modified for Channels 1 through 5, and a standard 70 kc discriminator was modified for Channel 6. These are designed to quiet normally with an input of about 50 mv, but an additional stage of amplification has been added to increase their sensitivity to about 10 mv.

Crosstalk became a very serious problem, since the second harmonics of Channel 1 could fall into Channels 2, 3, or 4; those of Channel 2 into Channels 3, 4, 5, or 6; and so forth. Nonlinearities in the mixer would generate appreciable cross-modulation. In order to overcome this difficulty, a biased four-transformer ring modulator is used for mixing (Figure 11). Rather than one center-tapped input transformer, two separate transformers are used; bias is applied to the midpoint of one secondary to balance out the input signal. In addition, balancing potentiometers were used in the primaries of the two output transformers. The crosstalk S/N ratio obtained by this technique, without daily adjustment, was better than 55 db. Optimum settings gave an additional 10 db improvement.

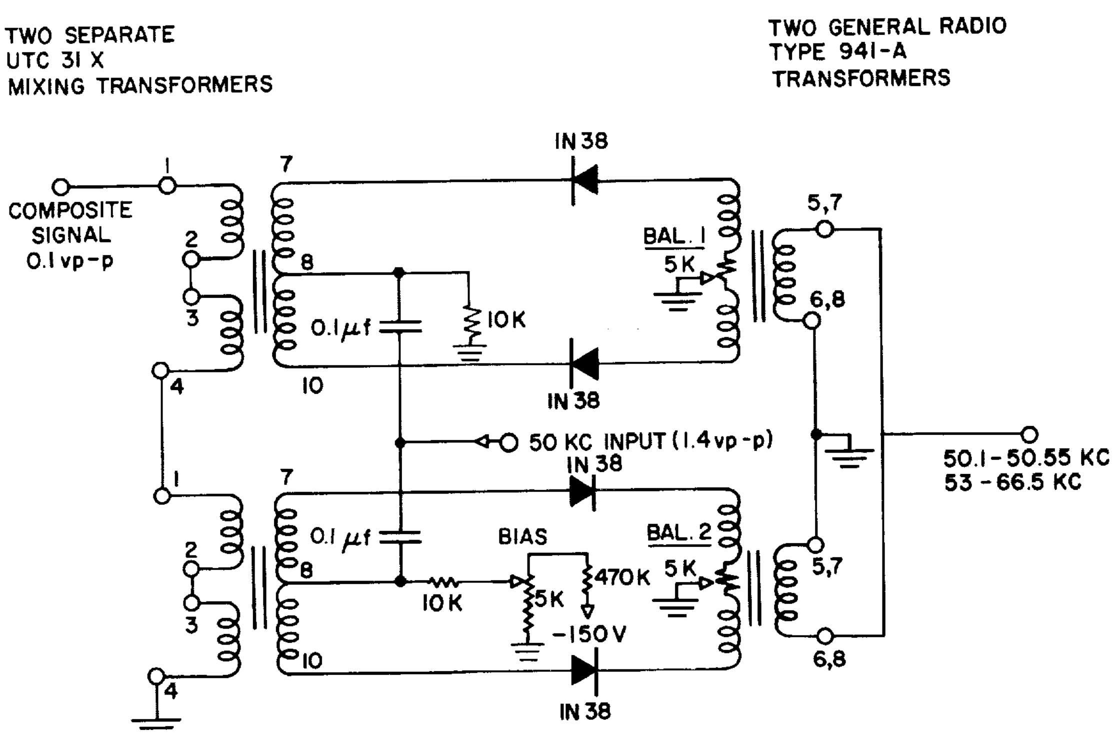
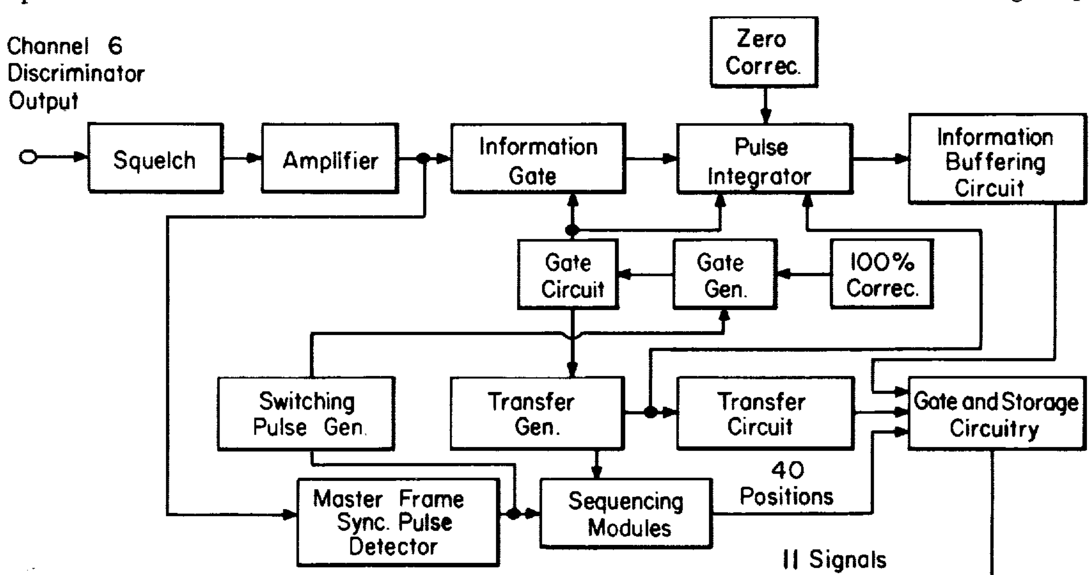


Figure 11—Schematic of ring modulator. The diodes were matched.

Compensation for tape recorder wow and flutter was applied to all six channels by discriminating the reference voltage, now 66.5 kc, and properly applying it to the individual channel outputs. Even with the phase distortion typical of crystal filters, corrections of 10 db or better were obtained. The Channel 6 output needs further decommutation before the wide field nonscanning radiometer data and the housekeeping data on this PAM channel are readily available.

A block diagram of the decommutator is shown in Figure 12. The squelch circuitry controls a switching relay that allows the signal to pass into the decommutator where the 40-channel input signal train is amplified to a standard level. The 120 percent calibration pulse provides frame synchronization every forty pulses. This controls the switching pulse generator and assures that the sequencing modules begin stepping at the proper time. The switching pulse generator opens a gate which allows the information to pass through to the pulse integrator. The integrated signal is transferred to the appropriate channel module through the information buffering circuit.

Automatic drift correction compensates for decommutator amplifier drift and for temperature variations in the Channel 6 subcarrier oscillator. The width of the gate pulse



Output Amplifiers					
Signal	Position	Signal	Position	Signal	Position
Black Cone	1, 6, 11, 16 21,26,31,36	Wide Field Reference	4, 9, 14, 19 24,29,34,39	50 Percent Calibration	20
White Cone	2, 7, 12, 17 22,27,32,37	Package Temp.	5	Pressure	25
		100 Percent Calibration	10	0 Percent Calibration	30
Black Cone	3, 8,13, 18 23,28,33,38	Radiometer Housing Temp.	15,35	120 Percent Calibration	40

Figure 12—Block diagram of decommutator

is varied inversely with variations in the output of the 100 percent calibration channel. Zero drift errors are eliminated by adjusting the reset potential of the pulse integrator with variations in the zero reference output.

The information buffering circuit supplies gated, integrated, and corrected information pulses to the gate and storage circuitry. The sequencing module, in conjunction with pulses from the transfer generator, permits each gate to select the proper information pulse for storage until the introduction of the next proper data sample. Outputs are obtained through amplifiers.

The five scanning radiometer channels, the wide field black and white cone data, the three reference temperatures, the timing reference, and the 100-μsec pulses for sun sensor, TV, and end-of-tape information are presented to the analog-to-digital converter.* The latter generates a magnetic tape in a special format for automatic data reduction on an IBM 7090 digital computer. The pulses cause special code words to be written on the digital tape; the TV pulses initiate the sampling, digitizing, and recording of the nonscanning radiometer data following the TV code word. Thus, radiation data can be correlated to picture data.

The five outputs of the scanning medium resolution radiometer are digitized sequentially within 200 μsec. Each radiation measurement is converted to seven binary digits to provide an accuracy better than 1 percent. The data sampling rate is sufficient to reproduce the radiation pattern. To achieve this, the five channels are digitized after 72 cycles of the 16.5 kc reference signal, about 8 times per real-time second. The equipment can double or halve this rate if it is so desired. Since the end-of-tape pulse stops the analog-to-digital converter automatically, the time of every sample on the tape is referenced very accurately to the time of interrogation. The six discriminator outputs and the modulated envelope of the reference signal are recorded in analog form for visual study.

COMPONENT DESCRIPTION

Subcarrier Oscillators

The subcarrier oscillators are phase-shift type oscillators whose output frequency varies from minimum to maximum as its balanced input voltage varies from zero to plus and minus 6 volts. The input is obtained from a push-pull amplifier whose output signal varies positive and negative, simultaneously, around ground. This push-pull system of signal transmission from the radiometer to the instrumentation canister minimizes noise pickup. The output voltage from each subcarrier oscillator is approximately 0.1 volt peak-to-peak into a 5.6 K ohm load.

The frequency ranges of the five channels are:

Channel 1—102 to 148 cps;
Channel 2—167 to 213 cps;

*The analog-to-digital converter was constructed by the Packard Bell Computer Corporation.

Channel 3—232 to 278 cps;
Channel 4—297 to 343 cps;
Channel 5—362 to 408 cps.

The tolerance on the minimum and maximum frequencies at room temperature is ±0.1 cps. Over the temperature range (0° to 60°C) used during the instrumentation testing, the tolerance on the minimum frequency was +3.0 and -0.0 cps, and on the maximum frequency, -3.0 and +0.0 cps. The calibration curve in Figure 13 shows modulating voltage vs. frequency at 0°, 25°, and 60°C for one of the oscillators. Since the five subcarrier oscillators are identical in principle, only one typical channel will be described in detail. Figure 14 is the block diagram of a subcarrier oscillator and Figure 15 is its schematic.

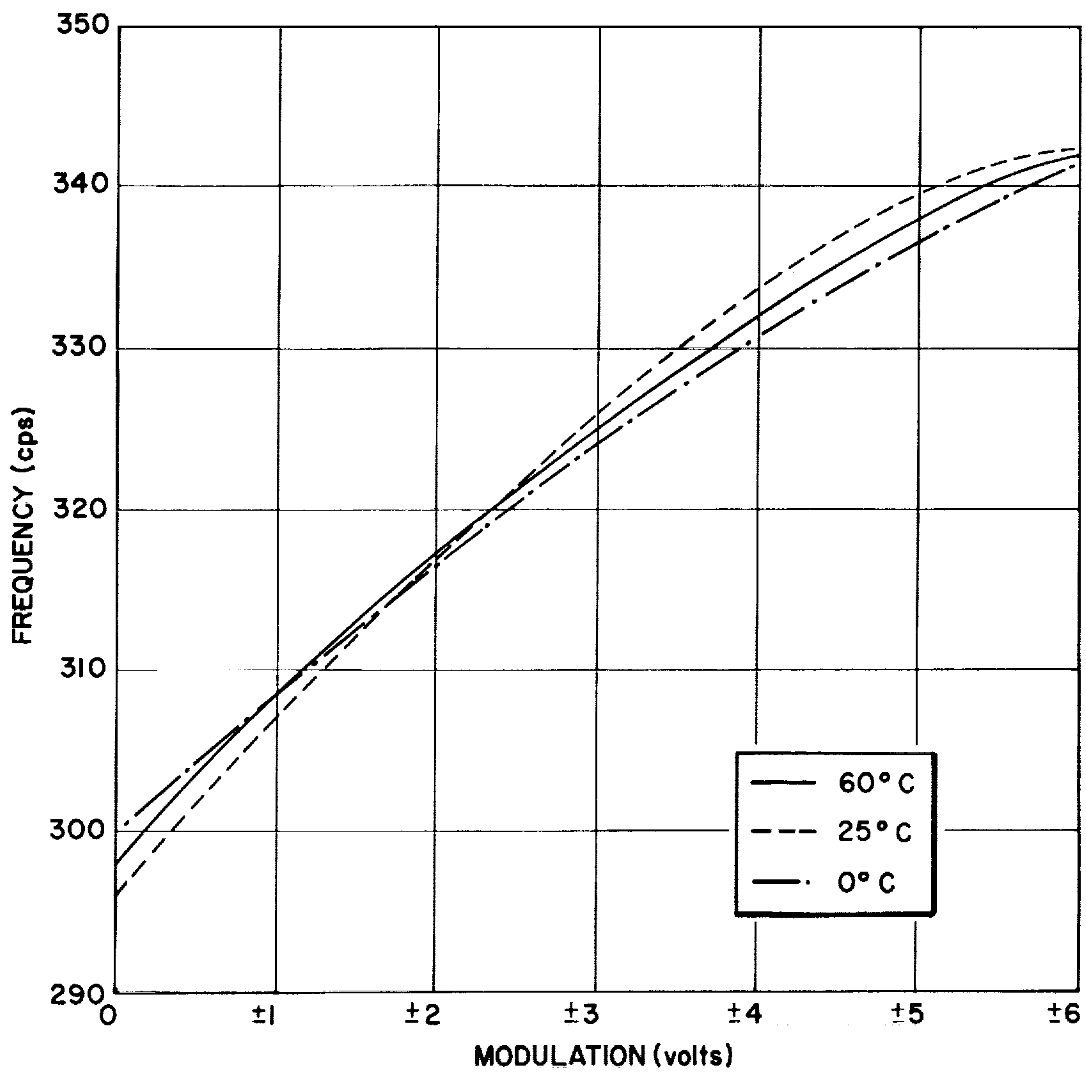


Figure 13—Sample calibration curve for a subcarrier oscillator, at temperatures of 0°, 25°, and 60°C

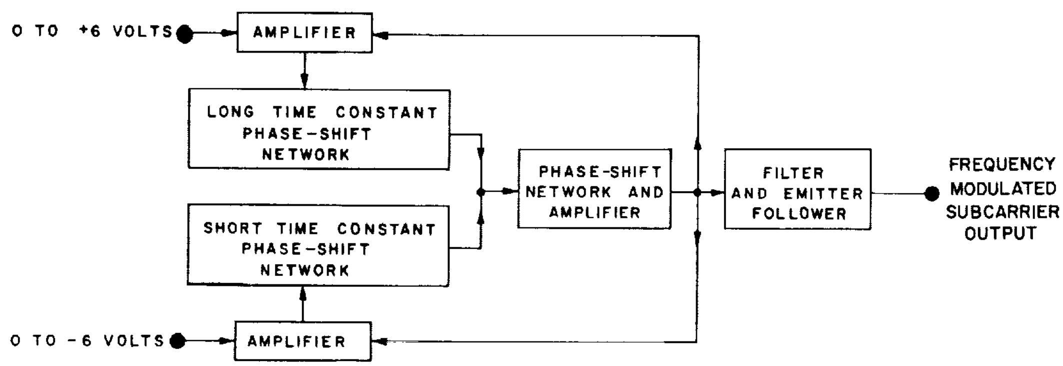


Figure 14—Block diagram of a subcarrier oscillator

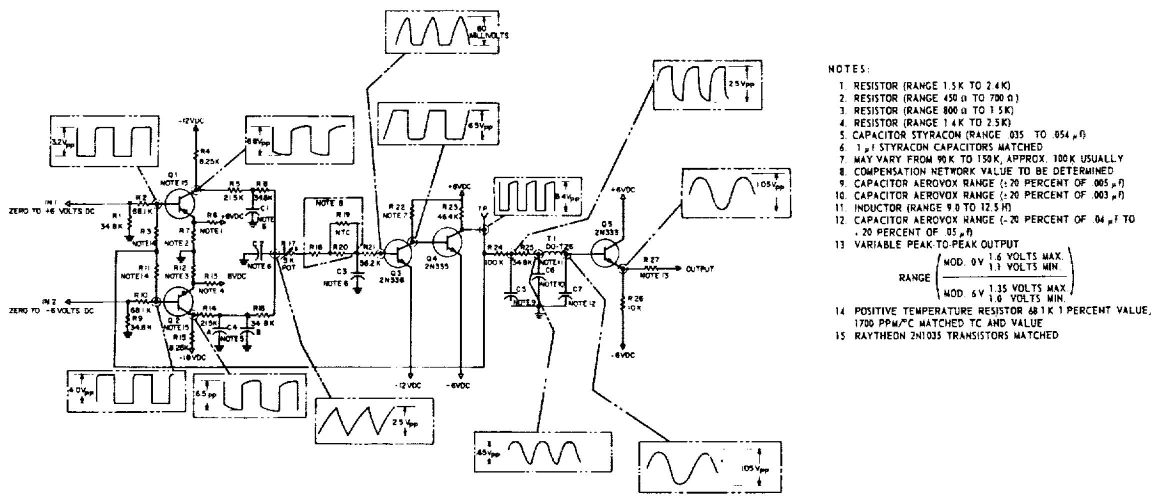


Figure 15—Schematic of a subcarrier oscillator. All waveforms are taken at 3 volt modulation.

Transistors Q_1, Q_2, Q_3, and Q_4 (Figure 15) comprise a stable phase-shift oscillator (Figure 14). The phase-shift networks are R_5 and C_1; R_{14} and C_4; R_8, R_{16}, and C_2; and R_{17}, R_{18}, R_{19}, R_{20}, and C_3 (Figure 15). Here dc coupling is employed so that negative dc feedback may be used for bias stabilization.

The heart of the oscillator is the modulating stage, consisting of transistors Q_1 and Q_2 and their associated circuitry. The desired operation is as follows: When no voltage is applied to either input, the minimum oscillator frequency should be produced. As input 1 approaches +6 volts and input 2 simultaneously approaches -6 volts (push-pull input), the output frequency approaches maximum. The frequency, ideally, will be a linear function of the modulating voltage and perfectly stable at any temperature between 0° and 60°C.

A brief analysis of the circuit will show how modulation is achieved. The modulator may be considered to consist of two amplifiers, each including one phase-shift network. As far as the oscillator is concerned, the two amplifiers are connected in parallel and are equivalent to one amplifier and a corresponding R-C phase-shift network. Note that the network associated with Q_2 has a shorter time constant than that of the other amplifier, Q_1. When no modulation is applied Q_1 is biased for an appreciable gain and Q_2 is biased close to cutoff. Thus, the R-C network associated with Q_1 will have the greater effect because of the greater gain, and its longer time constant dictates a relatively low frequency of oscillation. As modulation is increased Q_1 becomes biased for lower gain and Q_2 for higher gain until, at a modulation of ± 3 volts, Q_1 and Q_2 have equal gains. At this point the equivalent R-C time constant of these parallel amplifiers is midway between the time constants generated by either one separately, with a midrange frequency resulting. As modulation is increased further the gain of Q_1 is reduced and that of Q_2 increased, so the shorter time constant of the network associated with Q_2 becomes more dominant and frequency continues to rise. Finally, at the maximum modulation level of ± 6 volts, the frequency reaches the specified maximum. To prevent overmodulation in the presence of unexpectedly strong infrared signals, a Zener diode is placed at the radiometer output to limit the modulation voltage to a maximum of ± 6.5 volts; this prevents any possibility of interference between channels, which would make data reduction difficult or impossible.

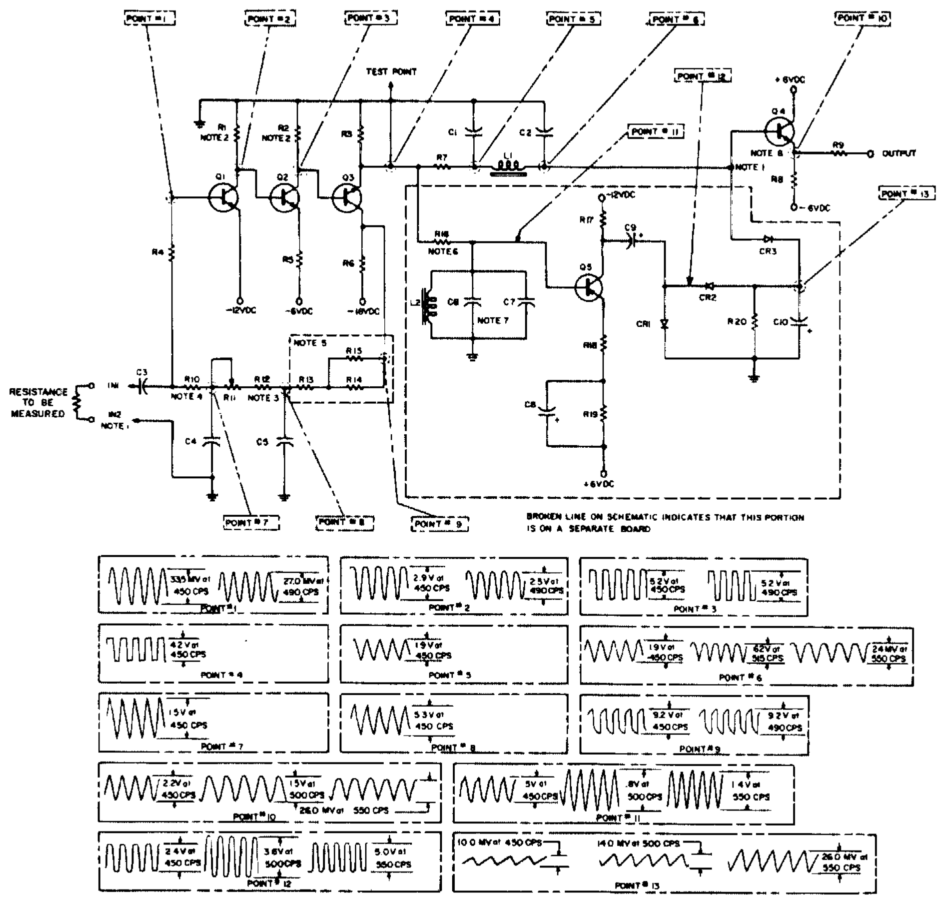
The oscillator output is taken from the collector of Q_4 where it appears as an 8-volt peak-to-peak symmetrical square wave. It goes through a low-pass filter, which cuts off sharply just above the maximum specified frequency, to remove third and higher harmonics. The resulting low-distortion sine wave is direct-coupled to buffer stage Q_5, from whose low impedance emitter the modulated output is taken.

Channel 6 Oscillator

The channel 6 phase-shift oscillator provides a carrier for time-shared information from the wide field radiometer, and for housekeeping and calibration data. The frequency output from this oscillator is varied by switching different resistances into the phase-shift network every 6 seconds. Make-before-break switch contacts create parallel resistances which cause lower frequency excursions between each data sample which result in negative-going pulses when demodulated.

The frequency range for Channel 6 is 427 to 483 cps. Frequency tolerances and the output voltage level are the same as for the five subcarriers just described.

The circuit (Figure 16) consists of a three-stage direct-coupled phase-shift oscillator in its simplest form, the output coming from the emitter of Q_3. The output waveform is quite square, owing to the large excess of loop gain. Series-R type phase-shift networks are used to close the dc path. The input, which is always in the form of a resistance



NOTES:

1. THIS PIN IS GROUNDED ON PROTOTYPE AND IR2. ON IR4, IR3, AND IR IT GOES TO BASE Q4.
2. VALUE DEPENDS ON SYMMETRY AT COLLECTORS.
3. THIS NUMBER "R12" IS TWO RESISTORS–A T.I. 1 PERCENT PLUS A T.I. SENSISTOR TO CONTROL RC TIME CONSTANT.
4. THIS NUMBER "R10" IS TWO RESISTORS–A T.I. 1 PERCENT PLUS A T.I. SENSISTOR TO CONTROL RC TIME CONSTANT.
5. COMPENSATION NETWORK VALUE TO BE DETERMINED.
6. THIS VALUE OF R16 IS DETERMINED BY OBSERVING THE OUTPUT AND ADJUSTING THE VALUE UNTIL CLIPPING OCCURS AT 490 CPS.
7. TUNE C6 AND C7 AT 560 CPS FOR DESIRED Q OF 30 AT 1KC IN IR-4, L2 IS UTC ML 5-2.5 H AND C6 AND C7 TOTAL .033 μf IN IR-3 AND IR-1, L2 IS RIXON .94 H AND C6 AND C7 TOTAL .085 μf.
8. OUTPUT BELOW 490 CPS (427 CPS TO 483 CPS) APPROX. 2Vpp ABOVE 490 CPS. SEE WAVEFORMS.
9. ALL WAVEFORMS TAKEN AT FREQUENCIES SHOWN ON WAVEFORMS SKETCHES.

PARTS LIST

R1 – } TO BE DETERMINED. NOMINAL } SEE NOTE 2
R2 – } R_1 20 K AND R_2 10 K
R3 – 4.64K
R4 – 56.2 K
R5 – 1 K
R6 – 15 K
R7 – 21.5 K
R8 – 14.7 K
R9 – TBD (TO BE DETERMINED)
R10 – 21.5 K
R11 – 5 K (TRIMPOT)
R12 – SEE NOTE 3
R13 – SEE NOTE 5
R14 – COMPENSATION NETWORK (TBD), SEE NOTE 5
R15 – SEE NOTE 5

(R1–R15: RN60C 1% 1/8 W OR T.I./C 1/8 S)

R16 – TBD, NOMINAL 75 K, SEE NOTE 6
R17 – 11 K
R18 – 560 Ω PTC + 270 Ω ¼ WATT
R19 – 9.1 K
R20 – 47 K

(R16–R20: ¼ WATT TYPE AB 5% VALUES)

Q1 – 2N335
Q2 – 2N336 (BETA NOMINAL 100)
Q3 – 2N1035
Q4 – 2N333
Q5 – 2N123 (BETA > 80 AT 1 MA)

L1 – UTC - DO-T7 (NOMINAL 28 H)
L2 – TBD, SEE NOTE 7

C1 – 0.047 μf STYRACON
C2 – 0.0025 μf
C3 – 0.047 μf }
C4 – 0.047 μf } MATCHED STYRACONS
C5 – 0.047 μf }
C6 – TBD } SEE NOTE 7
C7 – TBD }
C8 – 50 μf, 20 WVDC, TANTALUM
C9 – 1.0 μf, 20 WVDC, TANTALUM
C10 – 4.7 μf, 20 WVDC, TANTALUM

CR1 – 1N629
CR2 – 1N629 T.I. SILICON DIODES
CR3 – 1N629

Figure 16–Schematic of Channel 6 oscillator

between 350 and 1400 ohms (with the exception of the 120 percent level calibration resistor which produces the decommutator sync frequency), is applied in series with the phase-shift capacitor C_3, in order that one side of the input be connected to ground. Thus, frequency is a direct function of resistance and, with total bandwidth only 10 percent of the center frequency, the relation is nearly linear. It is important to note a safeguard inherent in this circuit: If for any reason the input should become open in one or more of the time-sharing switch positions only two phase-shift networks would remain. This could happen in the switch after long wear, or in the extensive wiring to scattered sensor locations. The 180 degree phase shift required to sustain oscillation cannot be obtained, at any frequency, with only two networks. Therefore, if the input did open, the oscillator would automatically shut off and there would be no interference with the other channels. The stability of this circuit, after compensation with the network consisting of R_{13}, R_{14}, and thermistor R_{15}, is typically ± 2 percent of bandwidth over the temperature range from 0° to 60°C.

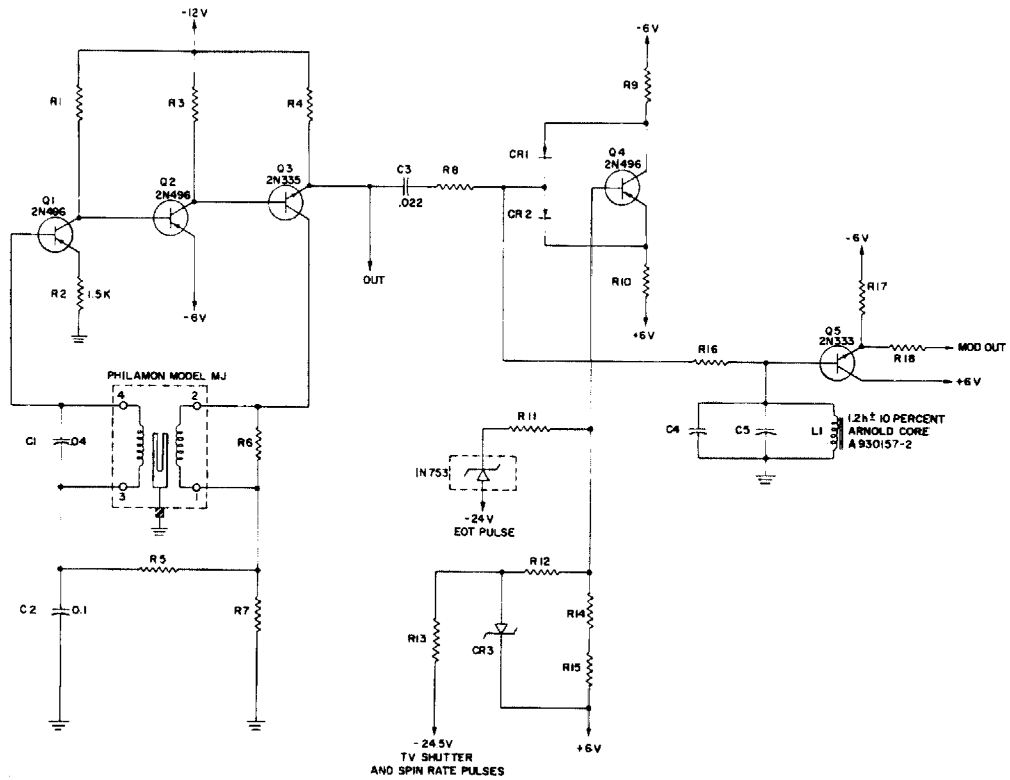
As with the oscillators comprising channels 1 to 5, the square wave is filtered to reduce the signal to its fundamental component and a low-impedance output is given by buffer stage Q_4. A refinement, indicated by the circuit within the broken line in Figure 16, was added to channel 6. Its purpose is to limit the output if the frequency tends to exceed the allotted band. A signal in the range of 520 to over 600 cps would be attenuated by more than 40 db by this circuit.

Channel 7 (Tuning Fork) Oscillator

The tuning fork oscillator produces a precise timing or "clock" frequency which is added to the other six channels before recording. It provides a stable frequency for running the synchronous record motor in the tape recorder and the chopper motor, in the radiometer. It also serves as the carrier for certain timing pulses which are applied as amplitude modulation. After transmission, it is used in the ground station to provide compensation for wow and flutter in the tape recorder.

Output voltage is approximately 0.15 volt peak-to-peak into a 5.6 K ohm load. A frequency of 550 cps, having a stability of one part in 10^4 over a temperature range from 0° to 50°C, is produced by a tuning fork oscillator utilizing an hermetically sealed, compensated tuning fork made by Philamon Laboratories. Amplitude modulation of the resulting square wave to -40 percent and approximately -95 percent is accomplished by a symmetrical clipper. A filter then removes harmonics, and the resulting sine wave passes through a buffer stage to the external resistive subcarrier oscillator summing network. Circuit operation will now be described in more detail, by discussing the oscillator, modulator, and filter-and-buffer sections.

In the oscillator circuit (Figure 17), the tuning fork, which is electrically equivalent to a tuned circuit with a Q of approximately 10,000, is placed in a regenerative feedback



PARTS LIST

R1, R2, R3 – TBD (TO BE DETERMINED)
R4 – 3.9 K
R5 – 91 K
R6 – 10 K TO 20 K
R7 – 2.4 K
R8 – 91 K
R9 – TBD
R10 – 5.6 K
R11 – 3.9 K
R12 – 2.2 K
R13 – 68 K
R14 – NEG. TEMP. COEFF. RES. (NTC)
R15 – 20 K
(R12–R15: TBD)
R16 – 91 K
R17 – 39 K
R18 – TBD

C1 – .04 μf
C2 – 1 μf
C3 – .022 μf
C4, C5 – TBD (MUST BE STABLE CAPACITORS)

Q1 – 2N496
Q2 – 2N496
(Q1, Q2: BETA 20-30 MATCHED)
Q3 – 2N335
Q4 – 2N496
Q5 – 2N333

Figure 17—Schematic of tuning fork oscillator

loop of a high-gain direct-coupled amplifier consisting of transistors Q_1, Q_2, and Q_3. R_6 shunts the drive coil to provide some damping and thereby improve the waveform. The value of this resistor is approximately twenty times the drive coil reactance so that, essentially, a current drive is maintained; this is necessary in order to avoid electrical phase shift which would cause a frequency error. R_5 provides negative dc feedback to give excellent amplifier stability, ac degeneration being prevented by capacitor C_2. C_1 attenuates high harmonics from the pickup coil, thereby improving the waveform. The feedback loop is completed by feeding the pickup coil voltage to the high-impedance input of Q_1. Sufficient gain is available to produce a symmetrical square wave with a rise time of about 30 milliseconds at the collector of Q_2. Note that Q_3 serves only to lower the output impedance and provides no voltage gain to the output directly.

Certain timing signals are telemetered as amplitude modulation on the 550 cps clock signal. These are:

(1) A -40 percent modulation for 0.5 second, once for every revolution of the spin-stabilized satellite, as a special sensor "sees" the sun;

(2) A TV frame indicator (telemetered with the IR data for later correlation of TV pictures with IR measurements) consisting of a -40 percent modulation, of 1.5 seconds duration, each time a programmed TV picture is taken;

(3) An end-of-tape pulse, a -95 percent (approximately) modulation of 1.0 second duration to indicate the end of IR data recording for each orbit.

Modulation is such that all except the end-of-tape signal may be removed in ground processing equipment by a clipping amplifier, to preserve continuity of the reference signal for timing purposes.

The square wave oscillator output signal to be modulated passes through a capacitor, to remove the dc component, and through a large resistor R_8, and then goes to the junction of diodes CR_1 and CR_2. These diodes act as simple clippers, CR_1 clipping the negative peak when the signal drops below the potential to which its anode is returned and CR_2 similarly clipping the positive peak. With no modulating voltage applied, Q_4 is in cutoff and the clipping levels are plus and minus 6 volts, the potentials to which the emitter and collectors, respectively, are returned. Since these clipping levels are above the peak signal input voltage, no clipping takes place and the signal remains unmodulated. In order to modulate to -40 percent, a potential of approximately -24 volts is applied to R_{13}. The end-of-tape modulation (approximately -24 volts) applied at R_{11} saturates Q_4, thereby reducing the signal nearly to zero. A 6-volt Zener diode is connected in series with this input to prevent forward-biasing of Q_4 when the modulation input is at ground potential.

From the modulator the signal passes through a bandpass filter to eliminate harmonics of the input square wave. Since the frequency is fixed, the filter's passband was made quite narrow (the tuned circuit Q is approximately 30 at 550 cps) and filtering is very effective. It is not so narrow, however, that the rise time of the modulation envelope is seriously affected.

From the filter the signal, now a good sine wave, is direct-coupled to buffer stage Q_5, the base of Q_5 being returned to ground through L_1. The relatively low output impedance of this stage feeds the subcarrier oscillator resistive summing network, of which R_{18} is a portion. The signal voltage at the emitter of Q_5 is about 2 volts peak-to-peak with no modulation applied.

Record Amplifier

The record amplifier circuit accepts a signal in the frequency range from 100 to 550 cps and prepares it for driving a tape head. Optimum equalization is applied to obtain a maximum signal-to-noise ratio when the tape recorder is operating at 0.4 ips (Figure 18). The output voltage is 0.4 volt peak-to-peak from the resistive mixing circuit with a 5.6 K resistor to ground. Overall efficiency and reliability are high.

The input signal is direct-coupled from the external resistive adding circuit whose dc potential is close to ground. The emitter current of Q_1 is about 1 ma (Figure 19). R_1 adjusts gain by controlling ac degeneration. The output of Q_1 is conventionally ac-coupled to the head-driving stage Q_2, which is biased at about 2 ma. A tuned series circuit bypasses the emitter resistor R_8, maximizing gain at its resonant frequency. The 550 cps signal is boosted 6 db by means of R_7. The collector of Q_2 is ac-coupled to the head to avoid any magnetizing direct current in the latter. To avoid head magnetizing transients R_9 maintains pin 2 at a potential of 12 volts while the record-playback head is disconnected during head switching.

Bias current is supplied to the other winding of the split winding record head by means of Q_1, which is coupled in the same manner as Q_2. Thus, the bias mixing is accomplished in the head itself. Capacitor C_5 tunes the head to the bias frequency to improve the efficiency and the bias current waveform; its effects are negligible at signal frequencies.

The erase bias oscillator is a simple feedback push-pull oscillator which uses the erase head as the inductance in a tuned frequency-determining circuit, the capacitance consisting of the two 0.15 μf feedback capacitors and the 0.5 μf capacitor, all in series. C_{14} is a small trimming capacitor which may be used to adjust the frequency to approximately 8 kc. The erase current is 80 ± 10 ma (70 ma is sufficient to reduce a saturated tape signal by 50 db). A small amount of the erase signal is taken through R_{15} for record head bias.

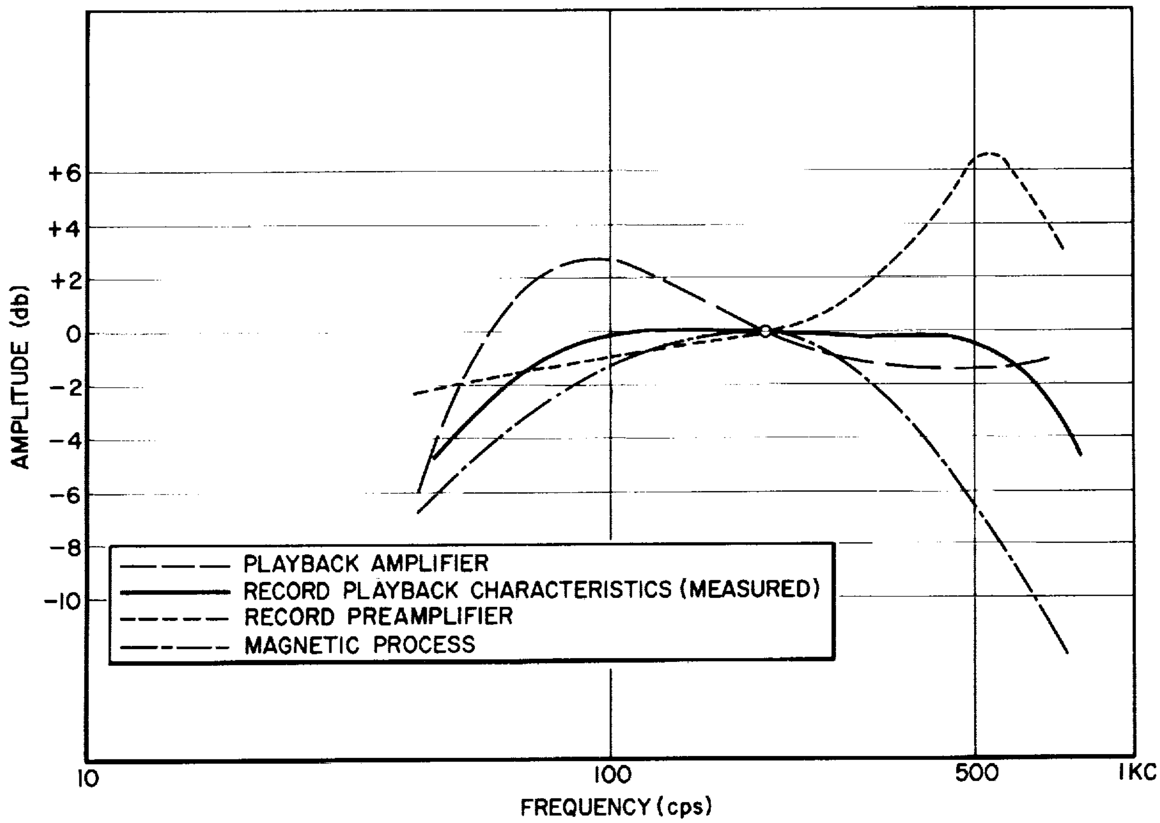


Figure 18—Record-playback equalization curve. All curves are referred to record frequency.

The erase and record play heads were built to the following specifications by Brush Instruments:

<u>Record play (BK-1251)</u>

0.25 mil gap

Full track (1/4" tape)

L = 84 mh ± 5 percent, 0°-60°C

R_{dc} ≈ 14 ohms

<u>Erase (BK-1252)</u>

Full track

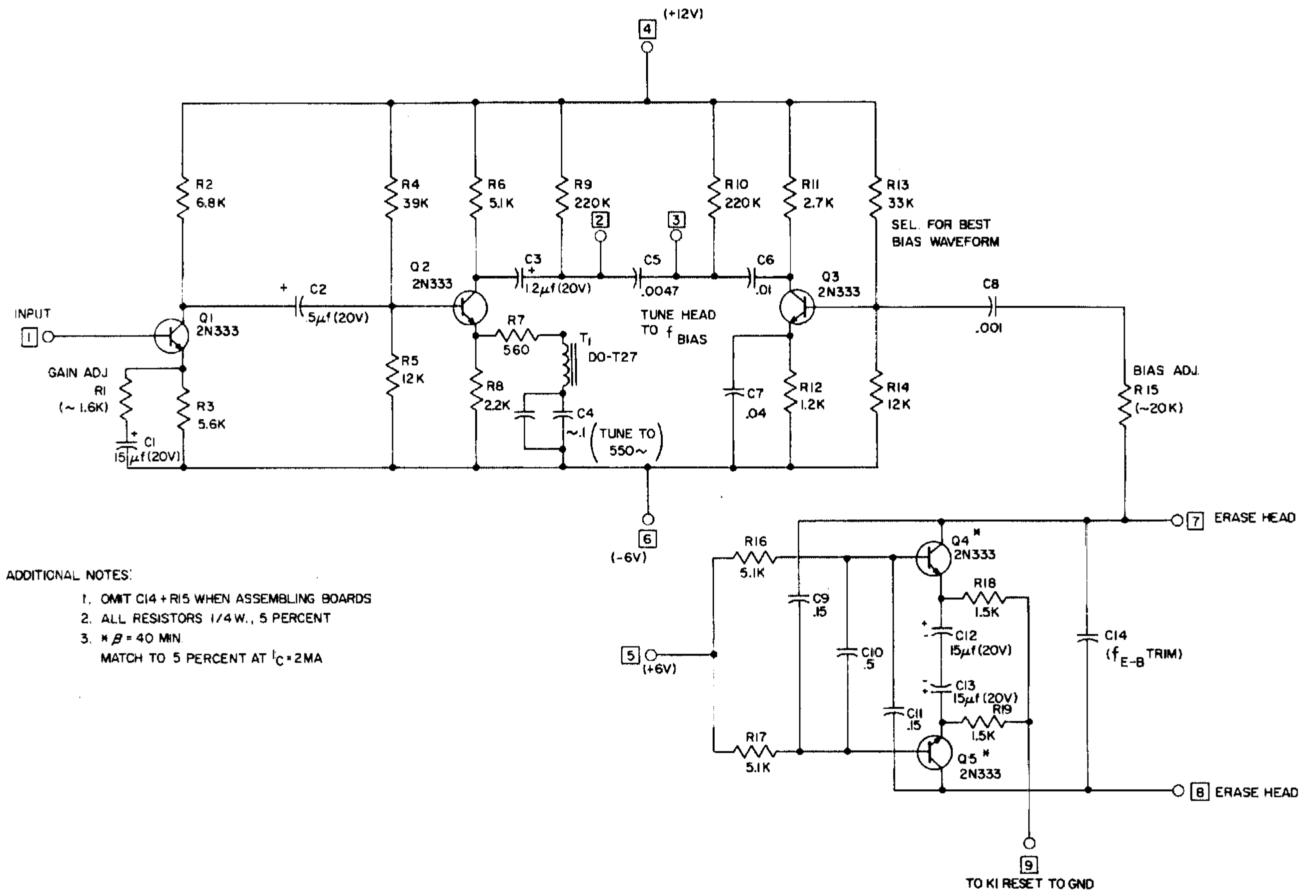
L = 6.2 mh ± 5 percent, 0°-60°C

R_{dc} ≈ 7.5 ohms

Note that both heads must have 2 windings balanced in inductance to within 2 percent with 4 leads brought out. The figures are for series-connected coils.

Playback Amplifier

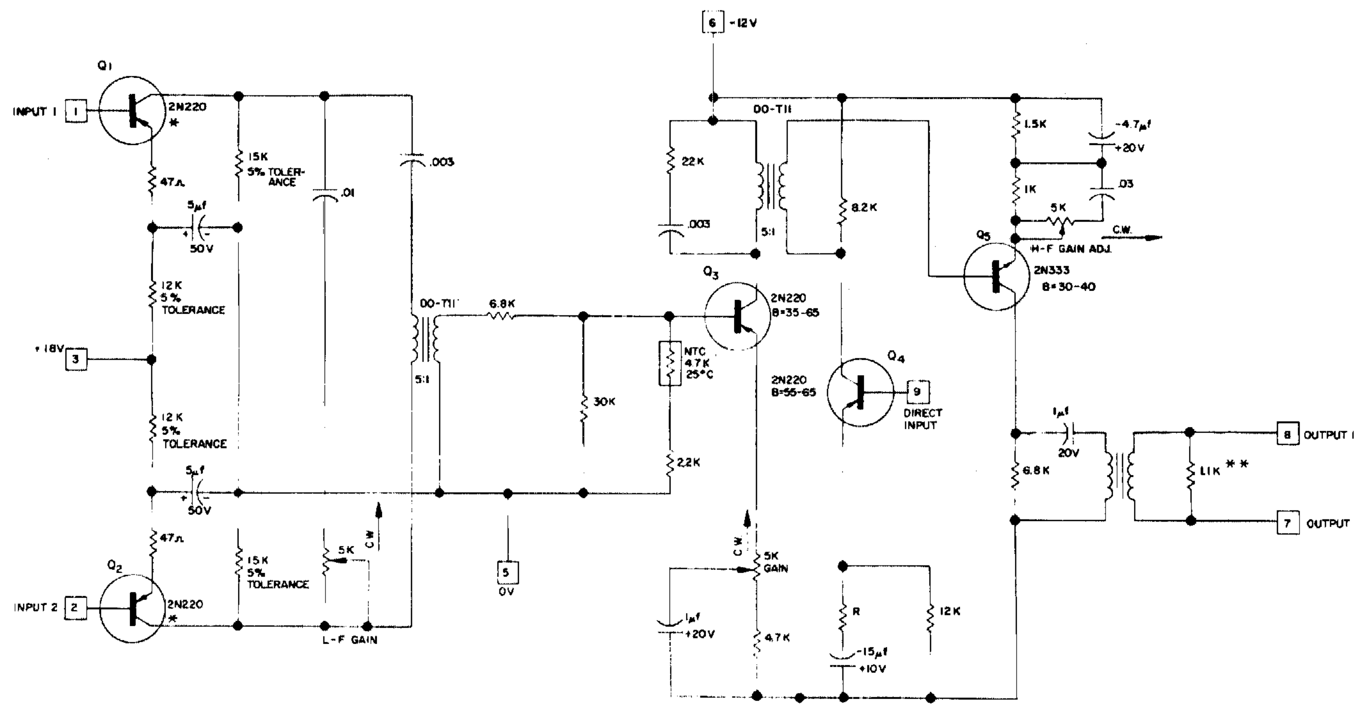
The playback amplifier (Figure 20) accepts two inputs of different levels and frequency ranges, amplifies and mixes these, provides a suitable and adjustable frequency characteristic, and delivers the resulting signal to a balanced low-impedance output.



ADDITIONAL NOTES:

1. OMIT C14 + R15 WHEN ASSEMBLING BOARDS
2. ALL RESISTORS 1/4 W., 5 PERCENT
3. * β = 40 MIN.
   MATCH TO 5 PERCENT AT I_C = 2MA

Figure 19—Schematic of record amplifier



ALL RESISTORS $\frac{1}{10}$ W. ALLEN-BRADLEY
POLARIZED CAPACITORS—MINIATURE TANTALUM
ALL OTHER CAPACITORS 100 V MINIATURE PAPER
*β = 70-90 MATCHED TO 2 PERCENT AT 0.5 ma I_e
NUMBERED SQUARES REFER TO CONNECTIONS TO CIRCUIT BOARD
POTS.—BOURNES "TRIMPOT JR"
ADJ. R FOR 0.25 V RMS OUTPUT WITH 0.4 V, P-P, 200 CPS, APPLIED AT DIRECT INPUT
**ADJ IN CONJUNCTION WITH "GAIN" POT. SO THAT TAPE SIGNAL (20 MV, P-P, 6 KC AT INPUTS 1 & 2) IS 6 DB HIGHER AT OUTPUT THAN DIRECT INPUT SIGNAL
NTC NETWORK MAY REQUIRE ADJUSTMENT

Figure 20—Schematic of playback amplifier

For minimum susceptibility to noise pickup, push-pull signal transmission from the playback head to the playback amplifier is used. This signal has frequencies from 3 to 16.5 kc. A positive 12-volt potential on the head leads biases the input stage to about 0.5 ma per transistor. The 12 K resistors in the emitter circuit, which are bypassed to ground by the 5 μf capacitors, provide dc degeneration for excellent stability. The 47 ohm resistors modify the input impedance so that there is essentially a matched condition at 16.5 kc for the best overall signal-to-noise ratio. These resistors also limit the peak charging current in the 5 μf bypass capacitors when the head, on which there is a low impedance + 12 volts dc, is switched onto the playback amplifier input. The 15 K resistors are collector loads. The use of ac coupling to the transformer, rather than dc, results in more stable gain and lower transistor noise. Proper choice of the coupling and emitter bypass capacitors provides a convenient means of limiting low frequency noise. The 0.01 μf capacitor and 5 K trimpot comprise a high frequency loss network with an adjustable cut-off frequency. This adjustment, in conjunction with the overall gain control, provides a low frequency gain control. At the secondary of the DO-T11 transformer, the signal becomes single-ended. The thermistor compensates for gain fluctuations with temperature, and must be adjusted for each individual board. The signal is direct-coupled to the next stage, whose total emitter resistance is chosen for a collector current of about 0.6 ma. The 5 K trimpot controls gain by adjusting the ac degeneration in this stage. The R-C network across the DO-T11 primary in the collector circuit provides a fixed low-frequency boost.

The real-time signal, whose frequency range is 100 to 550 cps, is direct-coupled to the base of Q_4. The dc potential of the signal applied is about -1.0 volt, so the bias current for this stage is about 0.6 ma. This stage normally gives no gain but serves as a buffer stage. Its collector swing is added to the signal from the second stage so that the sum of the two signals is passed on to the output stage. The emitter resistor R, which controls the degeneration of Q_4, is selected so that this input signal is nominally 6 db below the tape playback signal in the output.

The stability of Q_4 is sufficient to allow direct coupling to the output stage, which is biased at about 1 ma. The output transformer is ac coupled to avoid dc in the transformer winding, which would have a detrimental effect on the low-frequency response. Since the output was designed to feed a high impedance load, the 1100 ohm resistor was found useful in providing transformer damping and in further flattening the frequency response. In the emitter circuit there is, in addition to some dc degeneration which is due to the 1500 ohm resistor, a high-frequency gain control. This consists of a 0.03 μf capacitor, which bypasses the higher frequencies only and whose effectiveness is controlled by the series 5 K trimpot.

The input voltage is about 15 mv peak-to-peak from the tape recorder head and 0.4 volt peak-to-peak from the resistive mixing circuit. The output voltage is 1.4 volts peak-to-peak at 1100 ohms balanced. Figure 18 shows typical system frequency characteristics.

Tape Recorder

The tape recorder (Figure 21) is a low power two-speed recorder utilizing a continuous tape cartridge which stores 200 feet of 1/4 inch, 1.5 mil magnetic tape. The recorder weighs 4 pounds. Its external overall dimensions are: diameter 6.25 inches, and height 2.3 inches (Reference 7). The record system employs a two-phase hysteresis synchronous motor which requires less than 0.3 watt to operate. The record speed is 0.4 ips. The two phase frequency required to operate the record motor is obtained from a divide-by-four circuit which counts down the 550 cps reference oscillator signal (Figure 22). The single phase chopper motor is driven by one of these same sources. The playback system employs a dc motor requiring approximately 1 watt; the playback speed is 12 ips and is controlled to within ± 1 percent by a servo loop. A field produced by seven pairs of magnets imbedded in a flywheel is picked up by an inductor, and the resultant sinusoidal wave is fed to a discriminator centered at 583.3 cps (Figures 7 and 22). Any speed error produces a proportional dc voltage at the discriminator output. The servo loop is closed by adding this corrective voltage to the nominal dc motor voltage.

The capstan shaft is driven by the motor shaft, at a 30:1 reduction in speed, through a system of pulleys and polyester film belts. A spring clutch in the power drive system allows the record motor to operate continuously and be overridden by the dc playback motor during the playback cycle. The playback time, 200 sec, is controlled by a switch which operates only during the playback cycle. This switch rotates at a speed of one revolution in 200 sec, thus activating a microswitch which returns the system to the record mode.

Wow and flutter is maintained below 2.5 percent peak-to-peak over a bandwidth from 0 to 1000 cps. This is measured by recording a fixed frequency and playing it back through a discriminator whose output is proportional to speed variations. Filtering this output gives a wow and flutter measurement of 1.5 percent p-p from 0 to 300 cps and 2.2 percent p-p from 300 to 800 cps, with the overall spectrum as given above. This performance is made possible by using an extremely accurate gyro-type capstan assembly, with the capstan shaft having a maximum runout of 50-millionths of an inch.

RESULTS

Figure 23 shows the data from a portion of one orbit in analog form, with channels 1-7 appearing in order from top to bottom. The spin period is clearly recognizable on channels 1-5 as is the high contrast between the sky and the earth. The familiar time sharing pattern of the commutator presents itself on channel 6, and the bottom trace shows the sun modulation on the envelope of the reference signal.

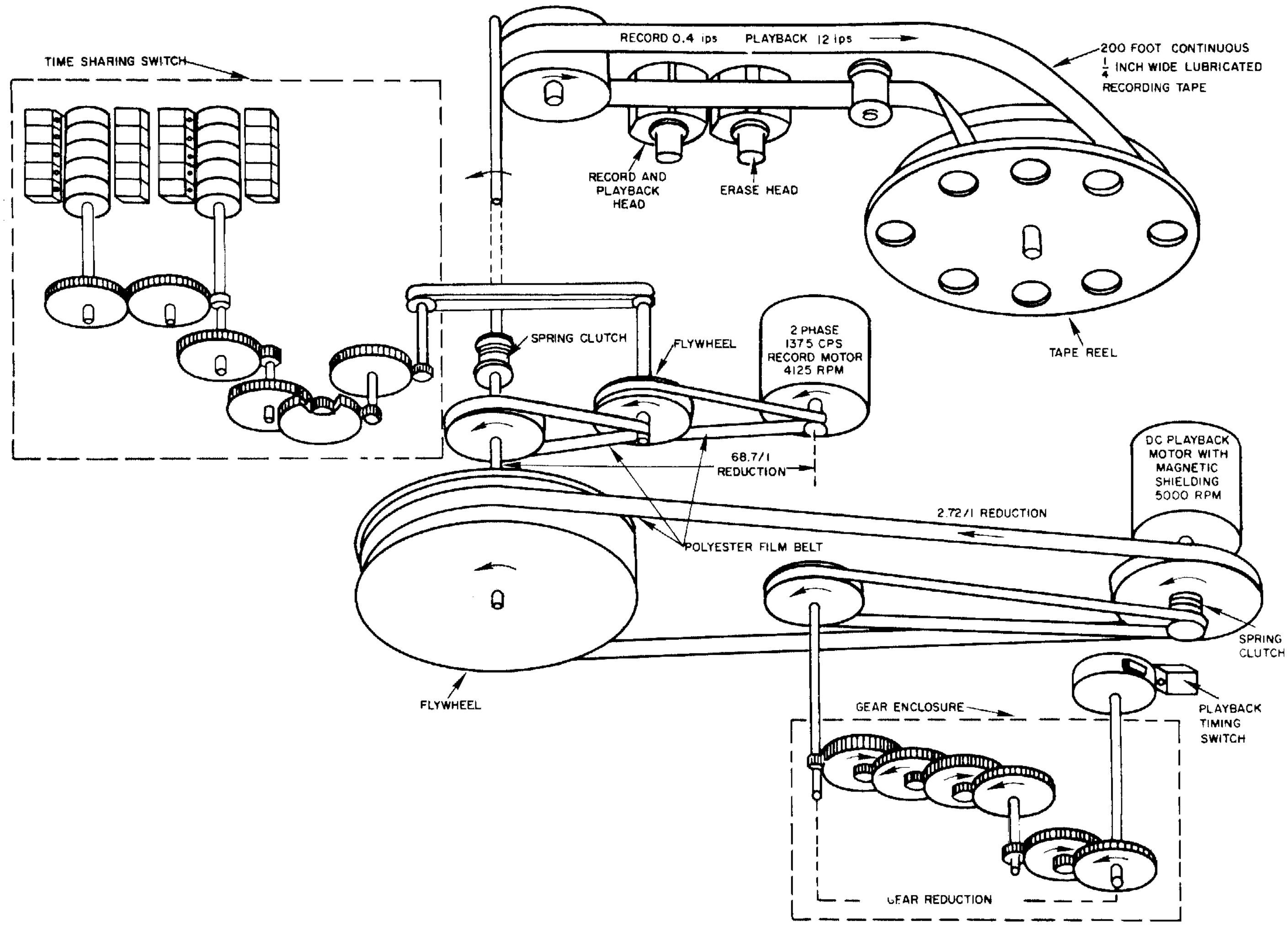


Figure 21—Diagram of the tape recorder

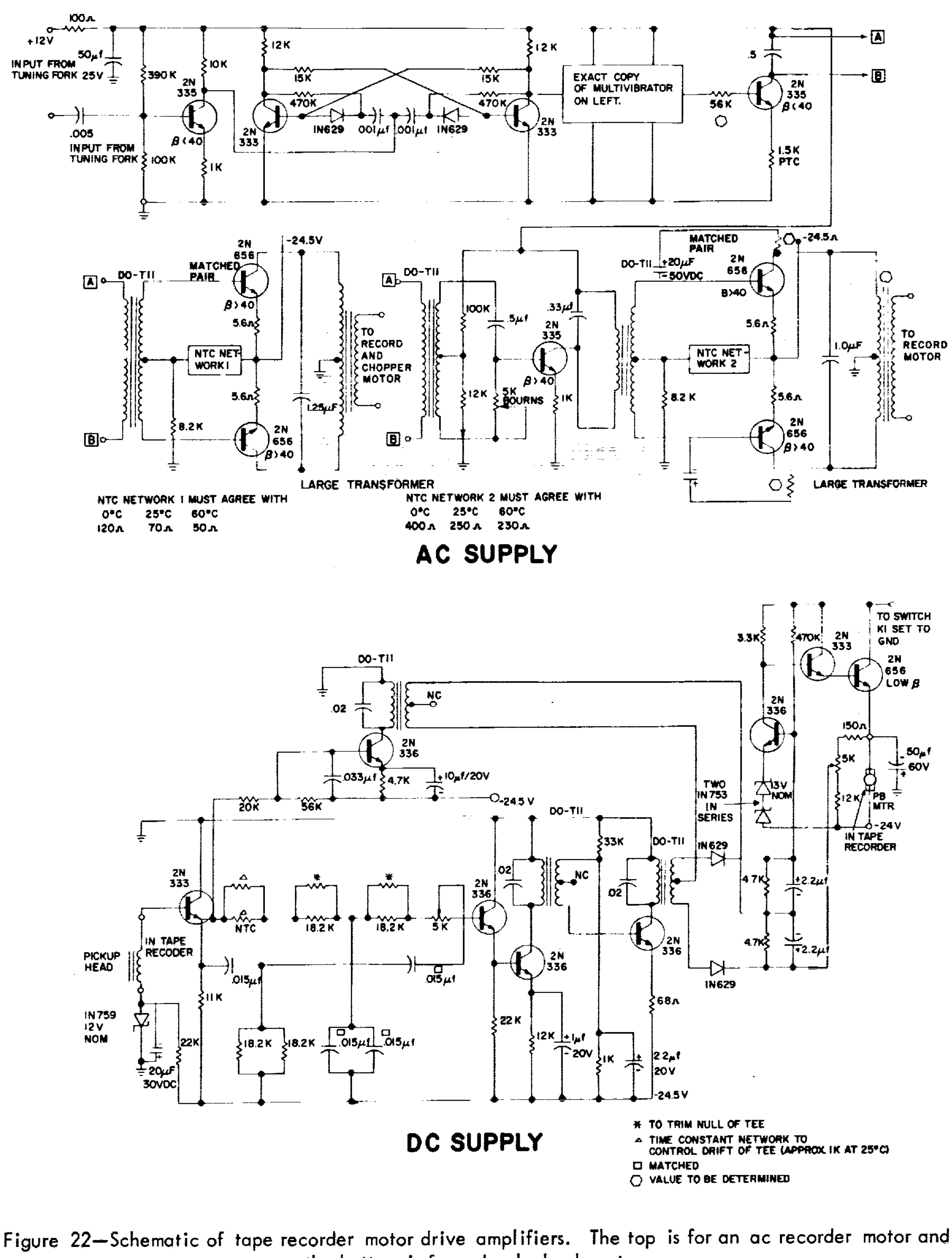


Figure 22—Schematic of tape recorder motor drive amplifiers. The top is for an ac recorder motor and the bottom is for a dc playback motor.

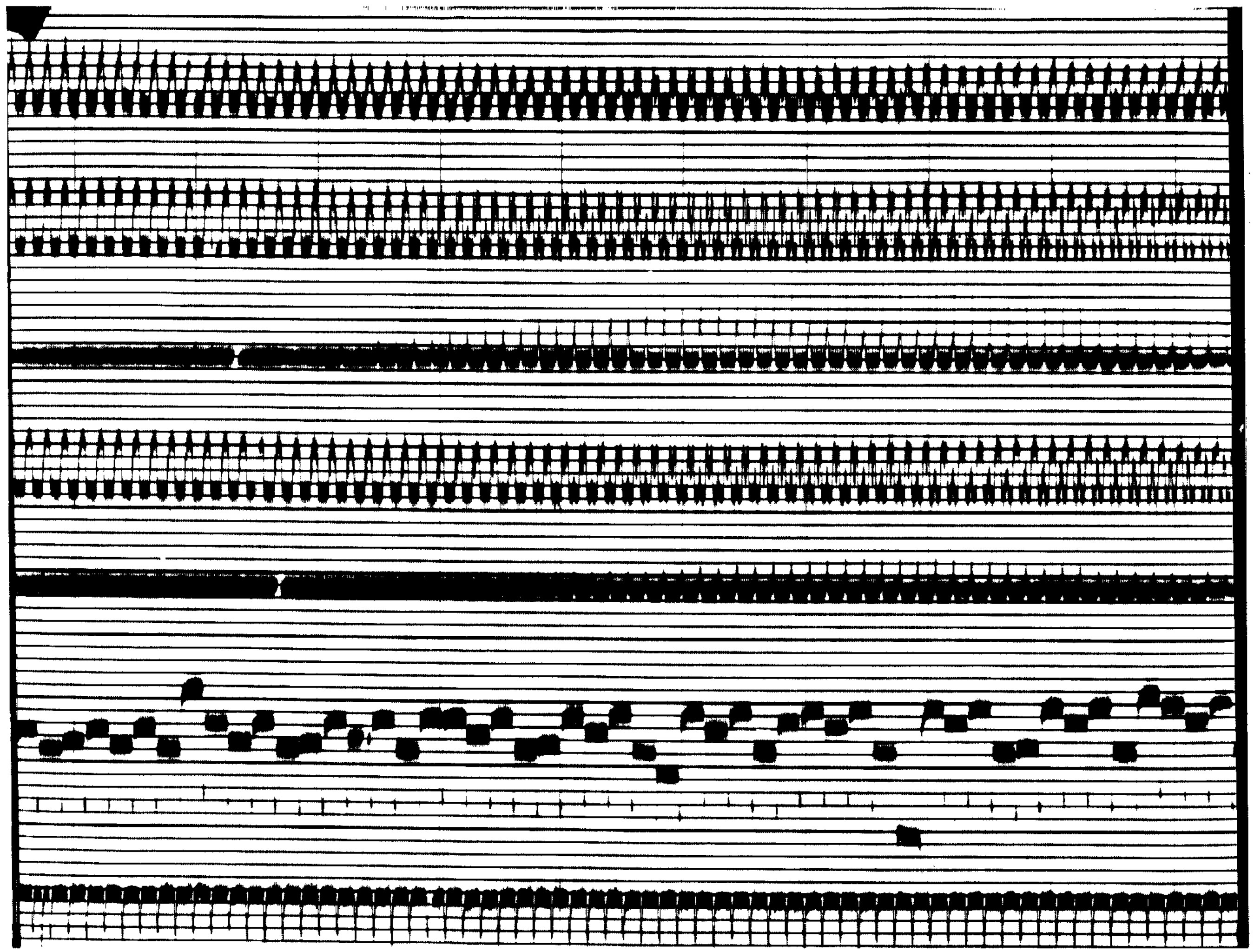


Figure 23—Sample of IR data in analog form for channels 1-7

With the aid of calibration charts, data (collected by the 8-12 micron thermal channel of the scanning radiometer) from the first orbit of TIROS II were used to determine the temperatures over an area between Australia and New Zealand at approximately local midnight. The optical axis was practically perpendicular to the earth's surface when it crossed the orbital plane. Figure 24 shows isothermal lines determined from the data and, superimposed on the map, curves outlining fronts as compiled by all available weather information. This is the first crude cloud cover map taken at local midnight by means of infrared radiation mapping. More complete discussions of these results have been published in References 8 and 9.

Close monitoring of temperature and pressure was maintained both for purposes of calibration and for general analysis. Figure 25 exhibits the long term average variation of package and radiometer housing temperatures. These smoothed-out fluctuations are related to the amount of time the satellite was exposed to the sun. Figure 26 is a graph of the variation of T_E and T_C over a two-orbit period. Figure 27 shows the variation of pressure in the sealed canister as the package temperature increased in its first steep rise — between orbits 754 and 826.

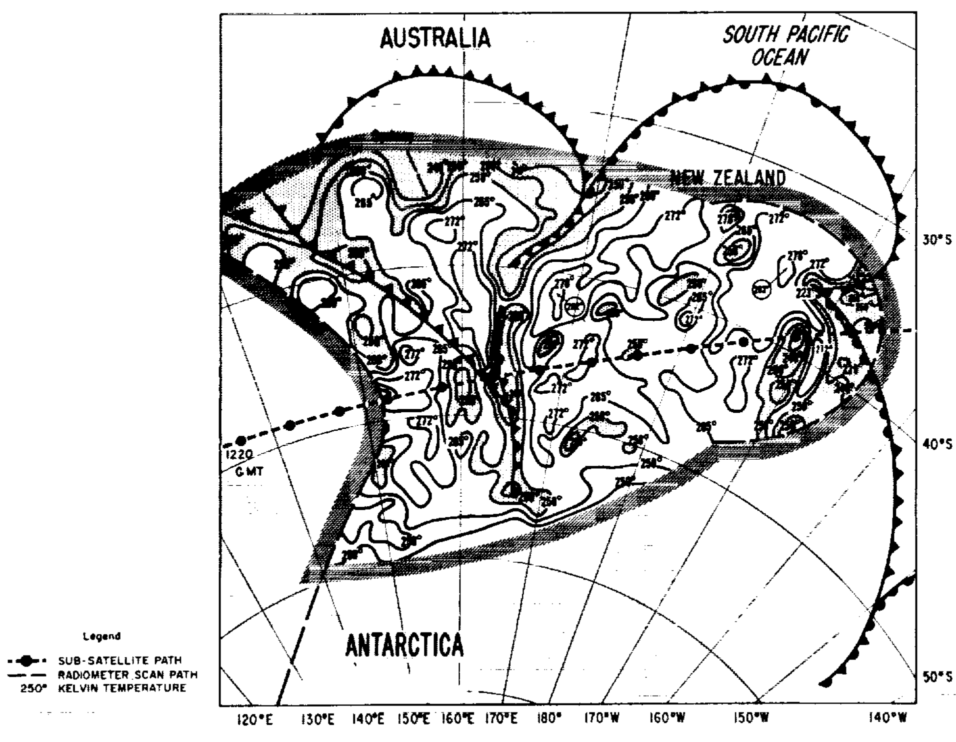


Figure 24—IR data over Australia and New Zealand on orbit 0 of TIROS II at local midnight

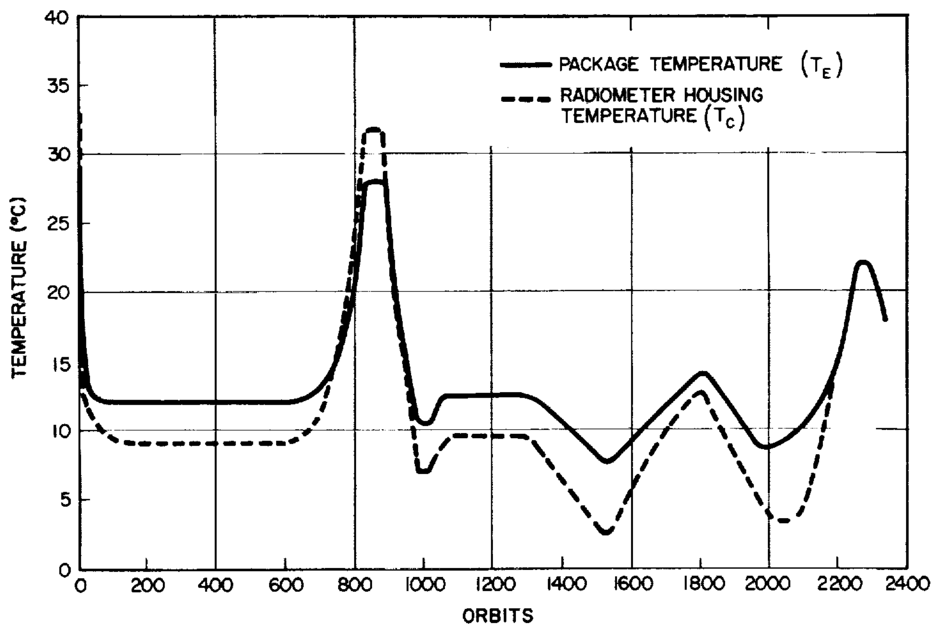


Figure 25—TIROS II satellite average temperature variation for 2325 orbits (>5 months)

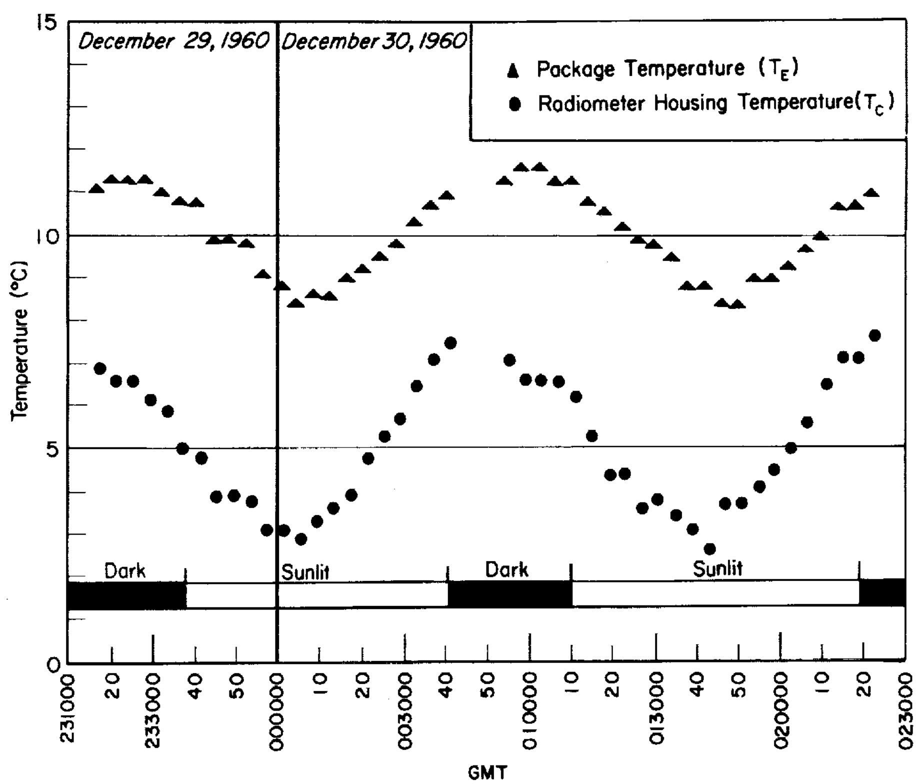


Figure 26—TIROS II satellite temperature variation during a two-orbit period (3 hr., 20 min.)

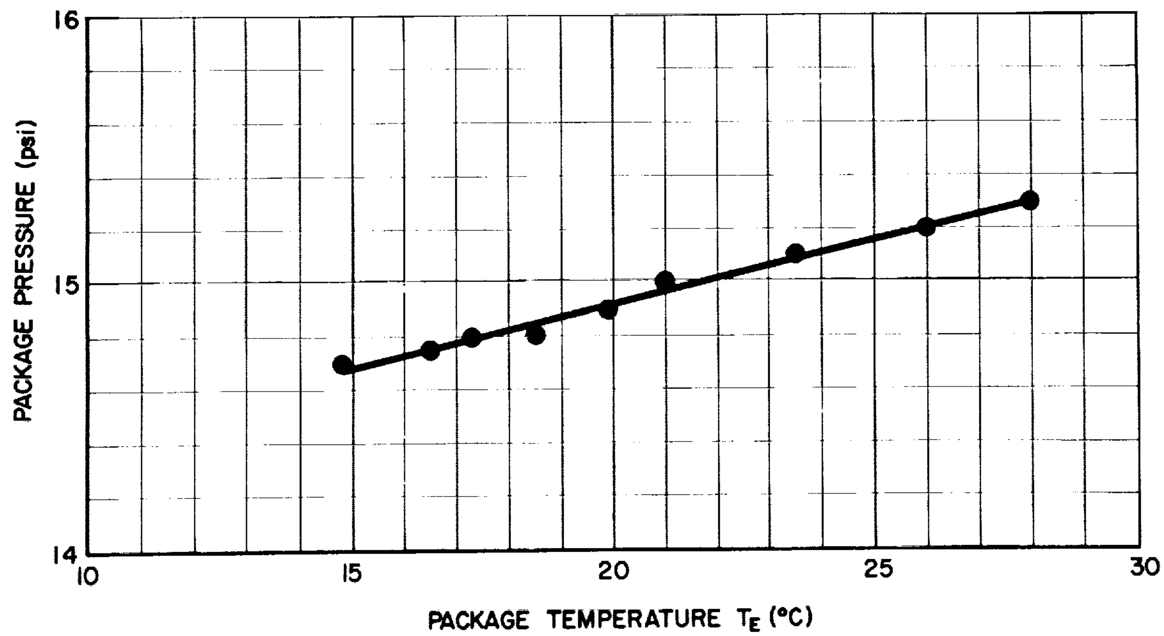


Figure 27—Variation of pressure vs. temperature in sealed IR instrumentation package from orbit 754 through orbit 826

CONCLUDING REMARKS

Although every TIROS satellite is expected to perform for a lifetime of 3 months in orbit, interrogations are continued past this time. TIROS II completed 2071 orbits (about 5 months) before the radiometer chopper motor failed. After about 9 months the canister, which was sealed at atmospheric pressure, began to leak. However, the electronics package, including the tape recorder, continued to function perfectly with no noticeable deterioration for another two months. Because of known degeneration of the satellite power supply, TIROS II was not interrogated again for six months, when it had been in orbit for 17 months. At this time, it was found that the radiometer chopper motor had restarted; the data (though noisier than during its useable lifetime) was clearly recognizable and readable. It is reasonable to assume that some of the noise was caused by tape deterioration after long use and loss of lubricant as the pressure decreased in the canister. As playback continued, the tape decreased in speed. This is probably attributable to the low power supply voltage. Volumes of TIROS II data have been digitized and are available for study by interested groups.

TIROS III has been in orbit for ten months, with its electronics package still functioning. TIROS IV has also been launched successfully and promises to have a long and useful life.

REFERENCES

1. Bandeen, W. R., et al., "Infrared and Reflected Solar Radiation Measurements from the TIROS II Meteorological Satellite," *J. Geophys. Res.* 66(10):3169-3185, October 1961; also NASA Technical Note D-1096, November 1961

2. Astheimer, R. W., DeWaard, R., and Jackson, E. A., "Infrared Radiometric Instruments on TIROS II," *J. Opt. Soc. Amer.* 51(12):1386-1393, December 1961

3. Hanel, R. A., and Wark, D. Q., "TIROS II Radiation Experiment and Its Physical Significance," *J. Opt. Soc. Amer.* 51(12):1394-1399, December 1961; also NASA Technical Note D-701, December 1961

4. DeWaard, R., and Wormser, E. M., "Description and Properties of Various Thermal Detectors," *Proc. IRE* 47(9):1508-1513, September 1959

5. Hanel, R. A., "Low Resolution Unchopped Radiometer for Satellites," *ARS J.* 31(2): 246-250, February 1961; also NASA Technical Note D-485, February 1961

6. Leavy, W. A., "A Time Sharing Switch for Spacecraft Telemetry Systems," NASA Technical Note D-1172, March 1962

7. Stark, K. W., Falwell, R. C., and White, A. F., "A Precision Endless Loop Recorder for Space Applications," NASA Technical Note, to be published

8. "Tiros II Radiation Data Catalog," National Aeronautics and Space Administration, Goddard Space Flight Center, and U. S. Weather Bureau, August 15, 1961, Vol. I "Tiros II Radiation Data Users' Manual," National Aeronautics and Space Administration, Goddard Space Flight Center, and U. S. Weather Bureau, August 15, 1961

9. Nordberg, W., et al., "Preliminary Results of Radiation Measurements from the TIROS III Meteorological Satellite," *J. Atmospheric Sci.* 19(1):20-30, January 1962; also NASA Technical Note D-1338, May 1962

NASA-Langley, 1962 G-187

NASA TN D-1293
National Aeronautics and Space Administration.
TELEMETERING INFRARED DATA FROM THE TIROS METEOROLOGICAL SATELLITES. J. F. Davis, R. A. Hanel, R. A. Stampfl, M. G. Strange, and M. R. Townsend. August 1962. 39p. OTS price, $1.00. (NASA TECHNICAL NOTE D-1293)

All the TIROS satellites contain television cameras which acquire cloud cover information. TIROS II and III also have scanning and fixed radiometers to measure infrared and reflected solar radiation from the earth and its atmosphere. The scanning radiometer is mounted so that the satellite's optical axis is inclined 45° to its spin axis. The spin motion provides a scan of individual lines of the earth's surface, and the orbital motion provides line advance. Spin and optical resolution are such that the information bandwidth is 8 cycles. Five choppers and filters separate the radiation into five channels whose outputs modulate the frequencies of five subcarrier oscillators. For maximum efficiency, each one is a basic

(over)

I. Davis, J. F.
II. Hanel, R. A.
III. Stampfl, R. A.
IV. Strange, M. G.
V. Townsend, M. R.
VI. NASA TN D-1293

(Initial NASA distribution: 17, Communications and sensing equipment, flight; 18, Communications and tracking installations, ground; 19, Electronics; 21, Geophysics and geodesy; 30, Physics, atomic and molecular; 47, Satellites.)

NASA

NASA TN D-1293
National Aeronautics and Space Administration.
TELEMETERING INFRARED DATA FROM THE TIROS METEOROLOGICAL SATELLITES. J. F. Davis, R. A. Hanel, R. A. Stampfl, M. G. Strange, and M. R. Townsend. August 1962. 39p. OTS price, $1.00. (NASA TECHNICAL NOTE D-1293)

All the TIROS satellites contain television cameras which acquire cloud cover information. TIROS II and III also have scanning and fixed radiometers to measure infrared and reflected solar radiation from the earth and its atmosphere. The scanning radiometer is mounted so that the satellite's optical axis is inclined 45° to its spin axis. The spin motion provides a scan of individual lines of the earth's surface, and the orbital motion provides line advance. Spin and optical resolution are such that the information bandwidth is 8 cycles. Five choppers and filters separate the radiation into five channels whose outputs modulate the frequencies of five subcarrier oscillators. For maximum efficiency, each one is a basic

(over)

I. Davis, J. F.
II. Hanel, R. A.
III. Stampfl, R. A.
IV. Strange, M. G.
V. Townsend, M. R.
VI. NASA TN D-1293

(Initial NASA distribution: 17, Communications and sensing equipment, flight; 18, Communications and tracking installations, ground; 19, Electronics; 21, Geophysics and geodesy; 30, Physics, atomic and molecular; 47, Satellites.)

NASA

NASA TN D-1293
National Aeronautics and Space Administration.
TELEMETERING INFRARED DATA FROM THE TIROS METEOROLOGICAL SATELLITES. J. F. Davis, R. A. Hanel, R. A. Stampfl, M. G. Strange, and M. R. Townsend. August 1962. 39p. OTS price, $1.00. (NASA TECHNICAL NOTE D-1293)

All the TIROS satellites contain television cameras which acquire cloud cover information. TIROS II and III also have scanning and fixed radiometers to measure infrared and reflected solar radiation from the earth and its atmosphere. The scanning radiometer is mounted so that the satellite's optical axis is inclined 45° to its spin axis. The spin motion provides a scan of individual lines of the earth's surface, and the orbital motion provides line advance. Spin and optical resolution are such that the information bandwidth is 8 cycles. Five choppers and filters separate the radiation into five channels whose outputs modulate the frequencies of five subcarrier oscillators. For maximum efficiency, each one is a basic

(over)

I. Davis, J. F.
II. Hanel, R. A.
III. Stampfl, R. A.
IV. Strange, M. G.
V. Townsend, M. R.
VI. NASA TN D-1293

(Initial NASA distribution: 17, Communications and sensing equipment, flight; 18, Communications and tracking installations, ground; 19, Electronics; 21, Geophysics and geodesy; 30, Physics, atomic and molecular; 47, Satellites.)

NASA

NASA TN D-1293
National Aeronautics and Space Administration.
TELEMETERING INFRARED DATA FROM THE TIROS METEOROLOGICAL SATELLITES. J. F. Davis, R. A. Hanel, R. A. Stampfl, M. G. Strange, and M. R. Townsend. August 1962. 39p. OTS price, $1.00. (NASA TECHNICAL NOTE D-1293)

All the TIROS satellites contain television cameras which acquire cloud cover information. TIROS II and III also have scanning and fixed radiometers to measure infrared and reflected solar radiation from the earth and its atmosphere. The scanning radiometer is mounted so that the satellite's optical axis is inclined 45° to its spin axis. The spin motion provides a scan of individual lines of the earth's surface, and the orbital motion provides line advance. Spin and optical resolution are such that the information bandwidth is 8 cycles. Five choppers and filters separate the radiation into five channels whose outputs modulate the frequencies of five subcarrier oscillators. For maximum efficiency, each one is a basic

(over)

I. Davis, J. F.
II. Hanel, R. A.
III. Stampfl, R. A.
IV. Strange, M. G.
V. Townsend, M. R.
VI. NASA TN D-1293

(Initial NASA distribution: 17, Communications and sensing equipment, flight; 18, Communications and tracking installations, ground; 19, Electronics; 21, Geophysics and geodesy; 30, Physics, atomic and molecular; 47, Satellites.)

NASA

NASA TN D-1293

phase-shift oscillator with a balanced input stage. The gain of the two balanced branches and the resultant phase shift in the network are functions of the input voltage, which thus determines the frequency of oscillation. Center frequencies are nonstandard and, to transmit the five channels within minimum bandwidth, frequency converters and crystal filters must be used for demultiplexing. A mechanical commutator samples the outputs from the nonscanning radiometer, thermistors, calibration resistors, and a pressure sensor. Each of these 6-second samples modulates, in turn, the frequency of a sixth subcarrier oscillator, a true phase-shift oscillator. These six signals and a reference oscillator signal are mixed and recorded on a single-channel tape recorder. Ground command initiates high speed playback and turns on an FM transmitter, which is modulated by the playback voltage. The composite signal is recorded on magnetic tape at a

(over)

NASA

NASA TN D-1293

phase-shift oscillator with a balanced input stage. The gain of the two balanced branches and the resultant phase shift in the network are functions of the input voltage, which thus determines the frequency of oscillation. Center frequencies are nonstandard and, to transmit the five channels within minimum bandwidth, frequency converters and crystal filters must be used for demultiplexing. A mechanical commutator samples the outputs from the nonscanning radiometer, thermistors, calibration resistors, and a pressure sensor. Each of these 6-second samples modulates, in turn, the frequency of a sixth subcarrier oscillator, a true phase-shift oscillator. These six signals and a reference oscillator signal are mixed and recorded on a single-channel tape recorder. Ground command initiates high speed playback and turns on an FM transmitter, which is modulated by the playback voltage. The composite signal is recorded on magnetic tape at a

(over)

NASA

NASA TN D-1293

phase-shift oscillator with a balanced input stage. The gain of the two balanced branches and the resultant phase shift in the network are functions of the input voltage, which thus determines the frequency of oscillation. Center frequencies are nonstandard and, to transmit the five channels within minimum bandwidth, frequency converters and crystal filters must be used for demultiplexing. A mechanical commutator samples the outputs from the nonscanning radiometer, thermistors, calibration resistors, and a pressure sensor. Each of these 6-second samples modulates, in turn, the frequency of a sixth subcarrier oscillator, a true phase-shift oscillator. These six signals and a reference oscillator signal are mixed and recorded on a single-channel tape recorder. Ground command initiates high speed playback and turns on an FM transmitter, which is modulated by the playback voltage. The composite signal is recorded on magnetic tape at a

(over)

NASA

NASA TN D-1293

phase-shift oscillator with a balanced input stage. The gain of the two balanced branches and the resultant phase shift in the network are functions of the input voltage, which thus determines the frequency of oscillation. Center frequencies are nonstandard and, to transmit the five channels within minimum bandwidth, frequency converters and crystal filters must be used for demultiplexing. A mechanical commutator samples the outputs from the nonscanning radiometer, thermistors, calibration resistors, and a pressure sensor. Each of these 6-second samples modulates, in turn, the frequency of a sixth subcarrier oscillator, a true phase-shift oscillator. These six signals and a reference oscillator signal are mixed and recorded on a single-channel tape recorder. Ground command initiates high speed playback and turns on an FM transmitter, which is modulated by the playback voltage. The composite signal is recorded on magnetic tape at a

(over)

NASA